BioPreferred®

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

Acknowledgments

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Asean
Biotechnology Innovation Organization
Carolina Nonwovens
Coca-Cola
Cotton Inc.
Eco-Products
Green BioLogics
Field to Market
Foodservice Packaging Institute
Ford Motor Company
Green Sports Alliance
Iowa State University's Center for Bioplastics and Biocomposites
National Wooden Pallet & Container Association
NatureWorks
Novozymes
Penford
Plastics Institute of America
Portland Trail Blazers
Procter & Gamble
Reebok International
SelfEco
SmartMulch
The Goodyear Tire and Rubber Company
United Soybean Board
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In 2009, Dr. Golden was presented the Faculty Pioneer Award by The Aspen Institute for his leadership in the field of sustainability education and research, and he was named by Ethisphere as one of the 100 Most Influential People in Business Ethics. He was appointed to the UN Lifecycle Management Task Force, and he was named an AT&T Industrial Ecology Fellow. Dr. Golden founded and co-directed the Sustainability Consortium and consults extensively for companies around the world

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Dr. 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. Dr. McConnell's professional service includes contributing to the Forest Products Society, the Society of American Foresters, and the Society of Wood Science and Technology.

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Dr. Brandon Morrison is Director of Strategic Initiatives, Division of Research at East Carolina University in Greenville, N.C. Brandon earned his Ph.D. in Earth and Ocean Sciences from the Nicholas School of the Environment at Duke University. His dissertation research examined the sustainability implications of the industrialization of the Earth's resources. He utilized lifecycle-modeling techniques to analyze the environmental impacts of utilizing biological feedstocks for energy production.

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Executive Summary

This report was prepared for the U. S. Department of Agriculture's (USDA's) BioPreferred® Program. The conclusions and recommendations are those of the authors and have not been endorsed by the USDA. The report is the fourth volume in a series of reports tracking the impact of the biobased product industry on the U.S. economy: 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] and the October 2016 report, *An Economic Impact Analysis of the U.S. Biobased Products Industry: 2016 Update.*[3] This report seeks to address seven important questions regarding the contributions of the biobased products industry in the United States:

(i) the quantity of biobased products sold;
(ii) the value of 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 effectively used, including identifying any technical and economic obstacles and recommending how those obstacles can be overcome

Although there have been several studies on the contribution of the biobased products sector to the global and European economies, this report is the third in a series to examine and quantify the effect of the U.S. biobased products industry from economic, job, and environmental perspectives, and provides an important update to past reports, and includes new information about biobased products exports. 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. We interviewed a broad spectrum of representatives of government, industry, and trade associations

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[1] Golden, J.S. and Handfield, R.B., "Why Biobased? Opportunities in the Emerging Bioeconomy," USDA BioPreferred® Program website, http://www.biopreferred.gov/BPResources/files/WhyBiobased.pdf, accessed April 2015.
[2] Golden, J.S., Handfield, R.B., Daystar, J., and McConnell, T.E. (2015). An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America. A Joint Publication of the Duke Center for Sustainability & Commerce and the Supply Chain Resource Cooperative at North Carolina State University. https://www.biopreferred.gov/BPResources/files/EconomicReport_6_12_2015.pdf
[3] 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, 2016. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf

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

A new addition to this report is that we also report on the value of the exports of U.S. biobased products. Exports make important contributions to the GDP, and since we are in a truly global economy, exports provide 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 IBISS World and the IMPLAN economic model. Rather than a single section, we have embedded a summary of the growth of the exports in each of the different sectors, which are 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
- Bioplastic Bottles and Packaging
- Biorefining
- Enzymes
- Forest Products
- Textiles

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

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 2016 was $459 billion, and employing 4.65 million workers. It was estimated that each job in the biobased industry supported 1.78 jobs in other sectors of the economy.

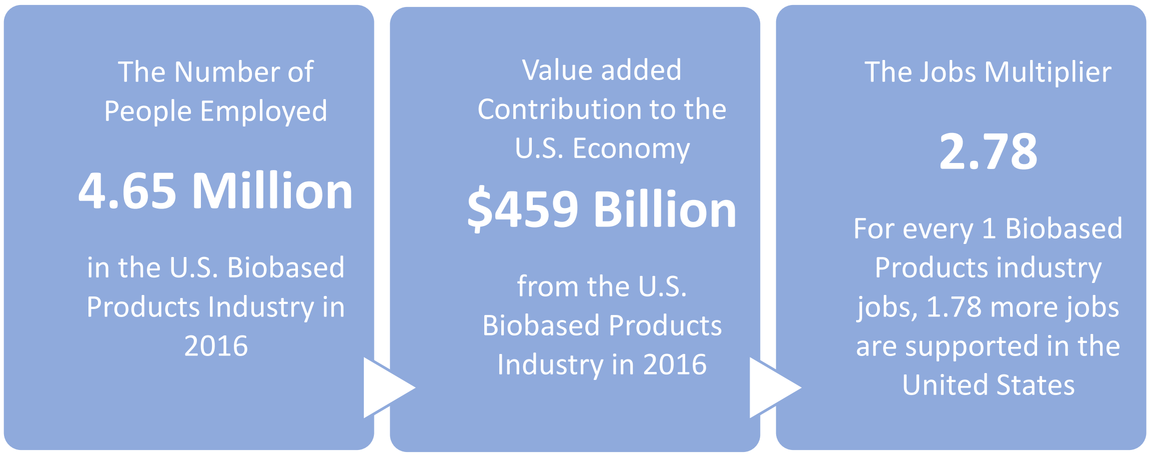

Figure 1: U.S. Biobased Products Industry Key Findings in 2016.

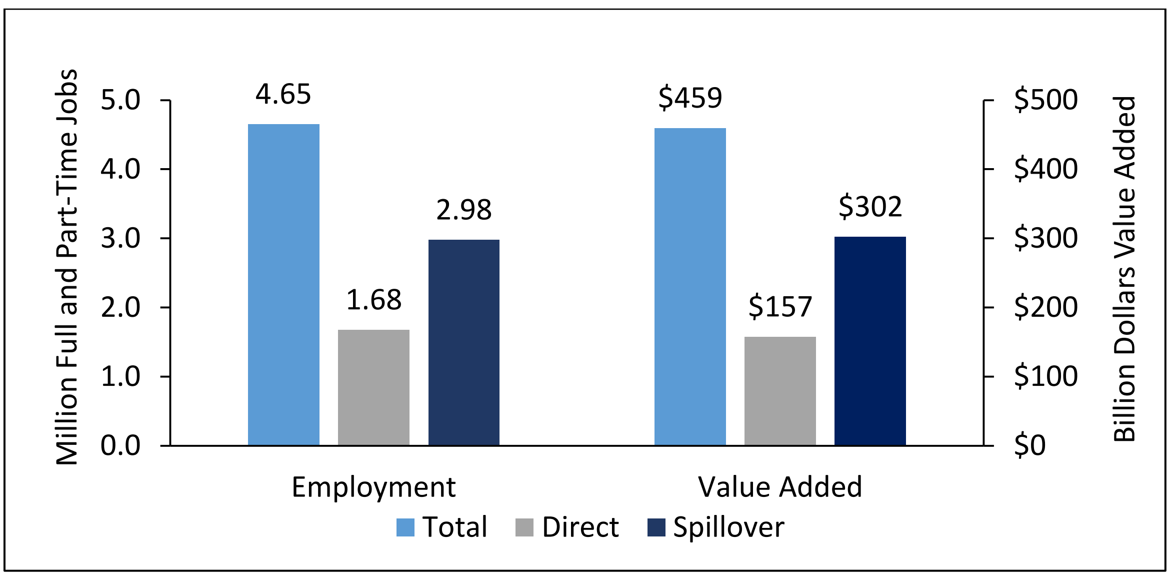

Figure 2 shows these numbers in more detail. The 1.68 million direct jobs supporting the biobased industry resulted in the formation of 2.98 million spillover jobs, including both indirect and induced jobs. Similarly, the $157 billion in direct value added had a spillover value added of $302 billion.

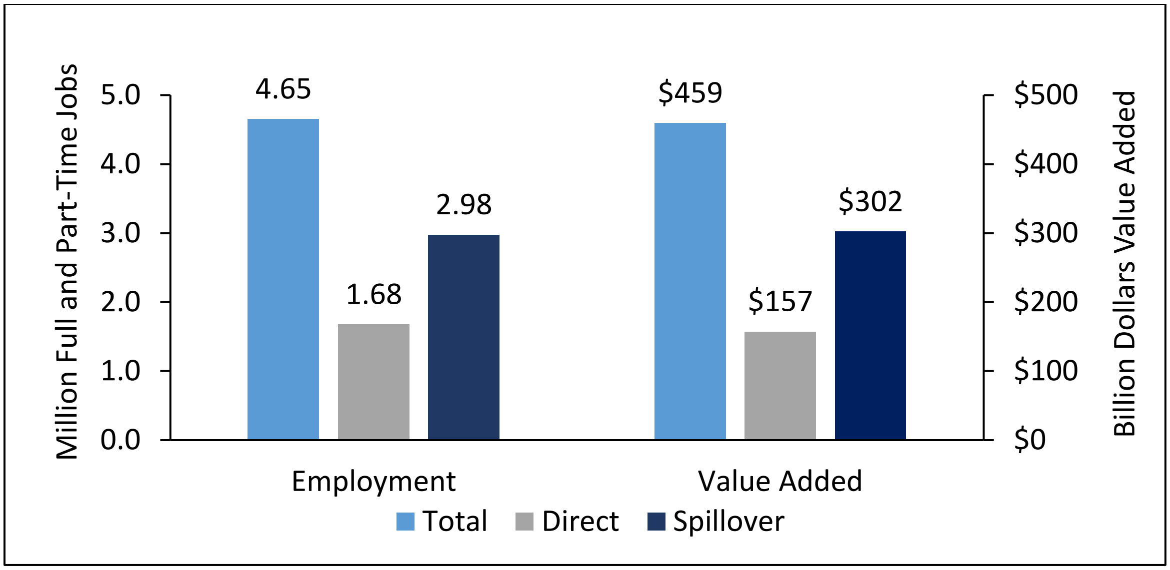

Figure 2: Total Employment and Value Added to the U.S. Economy from the Biobased Products Industry in 2016.

Figure 3 shows that the value added to the U.S. economy by biobased products was $459 billion, up from $393 billion in 2014, the current data available when the most recent report was written in 2016. This estimate compares favorably with the National Research Council's estimate of $353 billion for 2012. This is a significant increase of $66.4 billion, which is a 17% increase over 2014 levels. 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 sector, growing at a much faster rate than the economy and the GDP. This growth may be attributed to the increasing use of biobased materials in several sectors, as consumers are growing more cognizant of the need to use sustainable materials as well as modeling the enzyme industry as 100% biobased in this report. Figure 3 also shows that employment in the industry increased from 4.22 million jobs in 2014 to 4.65 million jobs in 2016**.** This represents an increase of 430 thousand jobs, representing an increase of more than 10% in the industry. As noted earlier, this may be due to the growth of the economy in general, but it also suggests that more people are finding employment in manufacturing and other related jobs that utilized biobased feedstocks and materials.

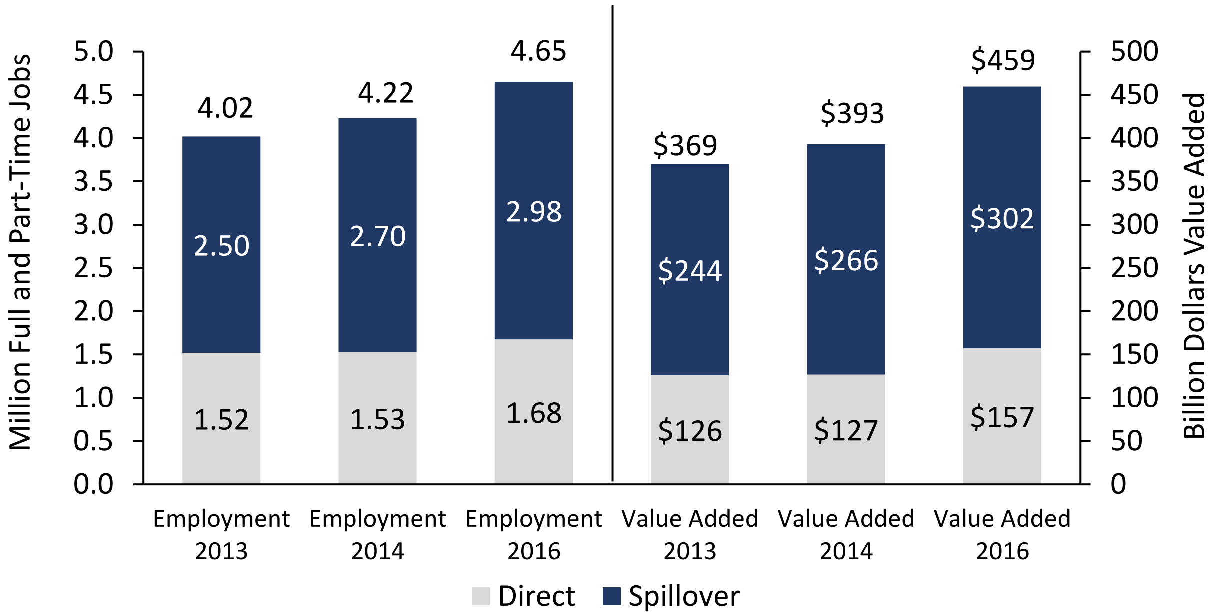

Figure 3: Economic Impacts of Biobased Products Industry in 2013, 2014, and 2016.

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

(i) The quantity of biobased products sold

While there is no database that tracks the "quantity of biobased products sold," the USDA BioPreferred Program has identified about 20,000 biobased products. This list contains very few forest products or traditional textile fiber products because these products only recently were included in the program. Therefore, we estimate that the actual number of biobased products is dramatically higher than the number 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. 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 $148 billion in 2016, suggesting that both the sales of 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 $459 billion, in 2016. This includes $157 billion in direct value added and $302 billion spillover value added. As mentioned earlier, this is a 10% increase over the 2014 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 4.65 million people in the United States in 2016. This included more than 1.68 million jobs directly in the biobased sector and 2.98 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 2013.

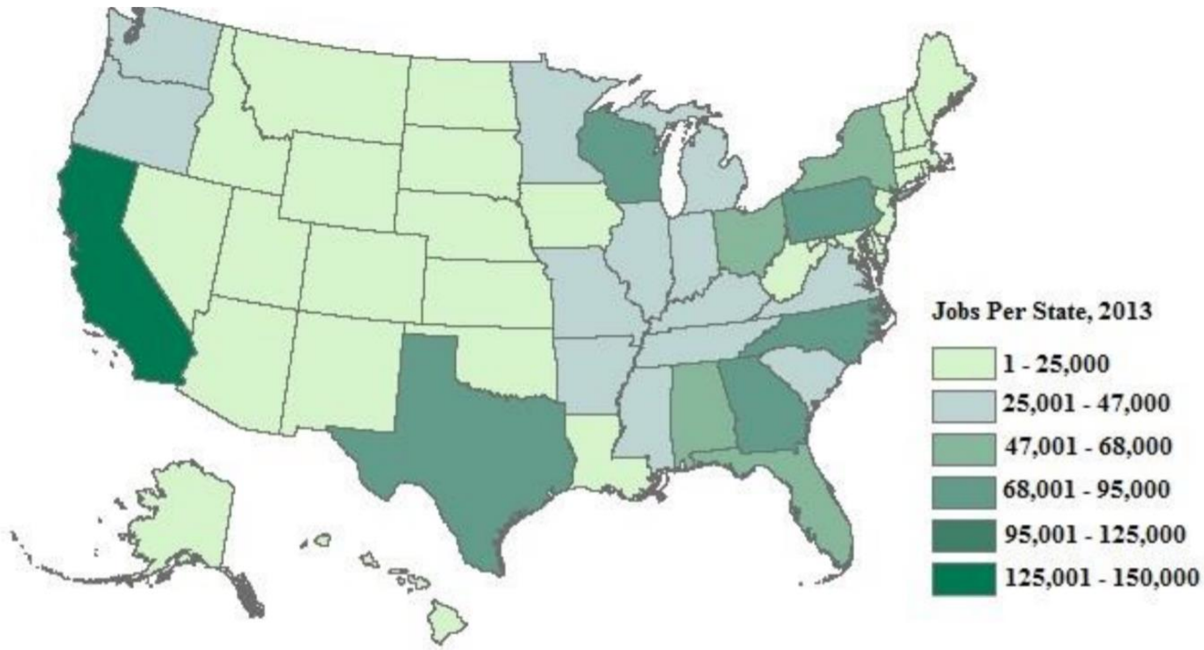

Figure 4: Jobs supported by the Biobased Products Industry by state. Note: Dark green and higher numbers indicate more jobs in the biobased products industry at the state level relative to the U.S. average. For more information, see section 2.

(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 2016 report to reflect economic growth. In 2016 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. We 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 2016 report and is updated in this report to reflect economic growth. A literature review showed that there are a wide range of GHG reductions resulting from the use of biobased products as an alternative to petroleum-based products. Using the upper range of GHG emissions reductions potential at an assumed 60% reduction, the analysis indicates that up to 12.7 million metric tons of CO_2 equivalents may have been reduced in 2016. 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 U.S. are consumed both in the U.S. and around the world. The economic contribution of biobased exports are calculated using the IMPLAN economic model and industry export data from IBIS World are estimated to be 555 thousand jobs and $57 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 to the biobased economy.

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

A wide range of both near-term and long-term opportunities are available to the public and private sectors for advancing the biobased products industry. These opportunities include creating production credits, increasing the visibility of the BioPreferred Program’s USDA Certified Biobased Product label, and the expansion of other related USDA programs. In this report, we present several important recommendations concerning how to augment and expand the growth of the biobased products industry. Our key recommendations include the following for the consideration of USDA and other associated public and private sector organizations.

- Improve the ability of the Federal Government, including the General Services Administration and other acquisition departments of federal agencies, to track the purchase of biobased products in acquisition systems. Currently, there is not a singular way of doing so, and it is difficult to accurately determine the increases in the use of biobased products by the Federal Government.
- Increase incentives to use biobased products and funding for research. Innovation is likely a key avenue for increasing the variety and efficacy of biobased products and fully utilizing biobased feedstocks. Many countries world-wide are investing in these technologies, and the U.S. should do so as well.
- Increase opportunities for private sector and university collaboration through on-going the National Science Foundation (NSF), USDA, and Department of Energy (DOE) funding grants. Many of the biobased innovations available today began in university

laboratories, and supporting the source of these important developments will be vitally important for enhancing the growth of the industry.

- Expand marketing and consumer education of the BioPreferred Program's USDA Certified Biobased Product label. Currently, many consumers are confused or are unaware of what a biobased product is, and they do not recognize or understand the label. While there are certainly benefits to having products labelled as USDA Certified Biobased, increased market recognition would help the biobased products industry grow and encourage more companies to pursue certification.
- Leverage the similar goals between the USDA and the DOE to cooperate on increasing the purchase of biobased products. Both agencies have similar objectives in terms of growth and less reliance on nonrenewable resources, and research supported by both agencies can provide greater power and increased success.

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. We conducted interviews with the following companies:

American Plastics Institute
Asean
Biotechnology Innovation Organization
Carolina Nonwovens
Coca-Cola
Cotton Incorporated
Eco-Products
The Goodyear Tire & Rubber Company
Green BioLogics
Field to Market
Foodservice Packaging Institute
Ford Motor Company
Green Sports Alliance
Iowa State University Center for Bioplastics and Biocomposites
National Wooden Pallet & Container Association
NatureWorks
Novozymes
Penford
Portland Trail Blazers
Procter & Gamble
Reebok
SelfEco
SmartMulch
United Soybean Board
U.S. Department of Agriculture
U.S. Department of Labor, Bureau of Labor Statistics
U.S. General Services Administration

Individuals were not compensated for sharing their knowledge and experience by participating in interviews. Based on those interviews, the report includes case studies of the development, manufacture, and use of biobased products with the following key innovative industrial partners:

- Asean
- Carolina Nonwovens
- Cotton Incorporated
- Eco-Products
- Foodservice Packaging Institute
- Ford Motor Company
- Goodyear Tire & Rubber Company
- National Wooden Pallet & Container Association
- NatureWorks
- Proctor & Gamble
- Reebok
- SelfEco

Glossary of Terms

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

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

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

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

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

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

(2) An intermediate ingredient or feedstock.

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

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

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

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 by-products. 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.[4]

Bioplastics: A type of plastics that are partially or fully biobased and/or biodegradable.

Biobased Bioplastic: A bioplastic that has some or all of its content produced from a renewable biomass sources. These plastics are derived 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: Bioplastics 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.

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

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.
By-product: Substance, excluding the principal product, generated during the manufacturing of the principal product. For example, a by-product 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.[5]
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.
Direct effects: Effects generated by the industry of interest through employment, value-added, and industrial output to meet final demands.
EIO-LCA: Economic input-output life cycle assessments quantify the environmental impact of a sector of the economy.
Emissions: Gases and particles that are released into the air or emitted by various sources.[6]
Employment: Considered in this report as full and part-time jobs in an industry.
Engineered wood products (EWPs): Wood composite products comprised of wood elements bonded together by an adhesive. EWPs are manufactured with assigned stress values for use in engineering applications.
Enzyme: A macromolecular that facilitates and speeds up chemical reactions. Enzymes act as catalysts for reactions that convert specific reactants into specific products with greater efficiency relative to the uncatalyzed reaction.
Ethanol: Produced from fermenting any biomass that contains a high amount of carbohydrates. It is typically made from starches and sugars but advanced generation technologies allow it to be made from cellulose and hemicellulose.[7].
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.[8]
Hemicellulose: Groups of complex carbohydrates that surround the cellulose component of the cell wall in plants. Hemicellulose also function as supporting material in the cell wall.
IMPLAN: Originally developed by the U.S. Forest Service and currently owned and operated by IMPLAN Group LLC (Huntersville, NC). The IMPLAN database and software system can be used to measure the economic effects of a given change or event in a region.
Indirect effects: The result of all sales by the supply chain of the industry of interest.

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[5] The Biofuels Handbook, ed. J. G. Speight (London: RSC Publishing, 2011), 524.
[6] U.S. Environmental Protection Agency (EPA), "Air Pollution Emissions Overview", U.S. EPA, accessed June 2016, https://www3.epa.gov/airquality/emissns.html. 8 Alberts B, Johnson A, Lewis J, et al., Molecular
[7] International Energy Agency (IEA), "Glossary", *IEA*, accessed May 2016, http://www.iea.org/aboutus/glossary/e/.
[8] U.S. Government Publishing Office (GPO) Electronic Code of Federal Regulations (e-CFR), Title 7 CFR part 3201.2, *e-CFR*, accessed June 2016, http://www.ecfr.gov/cgi-bin/text-idx?SID=c2eba5045067ce569f1d820d6d77b694&mc=true&node=se7.15.3201_12&rgn=div8.

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.[9]
Lignocellulose: Inedible plant material, mostly comprised of cellulose, hemicelluloses, and lignin. It includes agricultural waste, forestry waste, industrial waste, and energy crops.
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 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.
Total effect: The sum of the effects of all sales generated by all sectors, supply chains, and influence of employees spending within the study region. The sum of the direct, indirect, and induced effects.
Type I multiplier: The sum of direct and indirect effects, divided by the direct effect.
Type Social Accounting Matrix (SAM) multiplier: The Type SAM multiplier considers portions of value added to be both endogenous and exogenous to a study region. It is the sum of the direct, indirect, and induced effects divided by the direct effect. Type SAM multipliers generally are the preferred multipliers used in input-output analysis.
USDA Certified Biobased Product: A biobased product that has met the BioPreferred® Program's criteria to display the USDA Certified Biobased Product 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 consist of sales and excise taxes paid by individuals to businesses through normal operations). A sector's value added is its contribution to the study area's Gross Regional Product

[9] U.S. Government Publishing Office (GPO) Electronic Code of Federal Regulations (e-CFR), Title 7 CFR part 3201.2, e-CFR, accessed June 2016, http://www.ecfr.gov/cgi-bin/textidx?SID=c2eba5045067ce569f1d820d6d77b694&mc=true&node=se7.15.3201_12&rgn=div8.

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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) and the Agriculture Act of 2014 (H.R. 2642 2014 Farm Bill), the USDA BioPreferred Program is charged with transforming the marketplace for biobased products and creating jobs in rural America. 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 2018, there were approximately 14,000 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 that their purchases are biobased. Beginning in 2005 with its first designations of six product categories, the program has now designated 109 product categories representing approximately 13,000 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, including carpet and insulation, from all participating manufacturers, thereby encouraging manufacturers to compete to provide products with higher biobased content. With the Federal Government spending about $45 billion annually on goods and services,[10] 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 to the consumer market in February 2011. To date, more than 3,000 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 BioPreferred Program makes it simple for manufacturers to apply for the label and track their applications. The Program offers purchasers of biobased products a universal standard to assess a product's biobased content and their partnership with ASTM International ensures quality control and consistent results.

[10] "GSA Schedule Sale FY 2017 - Government Spending through GSA & VA Schedules," FEDSched, accessed 2018. http://gsa.federalschedules.com/resources/gsa-schedule-sales-fiscal-year-2017/.

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 was very limited. This is the third in a series of reports that addresses the impact of the biobased products industry on the U.S. economy. The first report in 2015[11] examined the number of jobs supported in the United States and value added by the biobased products industry to the U.S. economy. The website for this report received 520,000 download requests. The second report in 2016[12] 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 website for this report received more than 166,000 download requests

In this report, we have updated the national data from the previous reports and calculated the value added by exports for each sector of the biobased products industry. As was the case for the first two reports, we took a three-pronged approach to gathering information for this report. We interviewed a broad spectrum of representatives of government, industry, and trade associations involved in the biobased products industry so that we could understand the challenges and future growth potential for biobased products; we collected statistics from government agencies and the published literature on biobased products; and we used IMPLAN modeling software developed by the U.S. Forest Service to analyze and trace spending through the U.S. economy and measure the cumulative effects of that spending.

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

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

[12] 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, 2016. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf

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 with ranges varying from 1%, to 100% biobased depending on the sector. These estimates were formed based on published literature and information gathered through interviews.

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 the USDA undertake 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.

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, and jobs by sector, reports on the value added by exports in each sector, and discusses the potential for economic growth in the industry. We have interspersed case studies conducted over the course of this study, 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.

Environmental benefits of the biobased products industry are discussed in Section 3. Section 4 describes federal biobased procurement policies, including the BioPreferred Program, and how biobased products are tracked in federal acquisition systems. Appendix A describes the economic modeling framework using IMPLAN.

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 include major U.S. and global firms, total value added to the U.S. economy in 2016, 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 sub-sector also are 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 2016. The total contribution of the biobased products industry to the U.S. economy in 2016 was $459 billion and that the industry employed 4.65 million workers. Each job in the biobased products industry was responsible for supporting 1.78 jobs in other sectors of the economy. Figure 6 shows these numbers in more detail. The 1.68 million direct jobs directly supporting the biobased products industry resulted in 2.98 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 in 2013 to 2016.

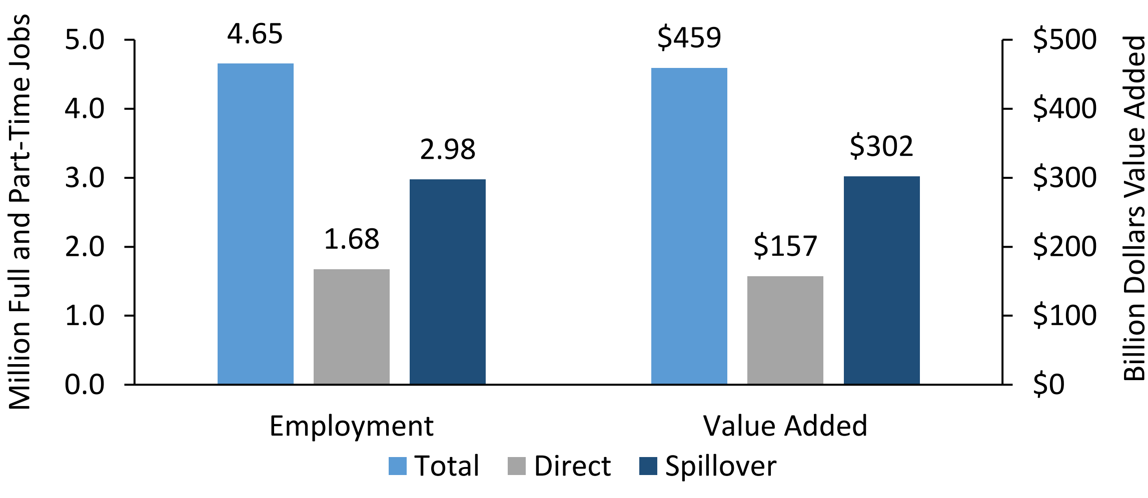


Figure 6: Biobased Products Industry contributions to U.S. Employment and Value Added in 2016.

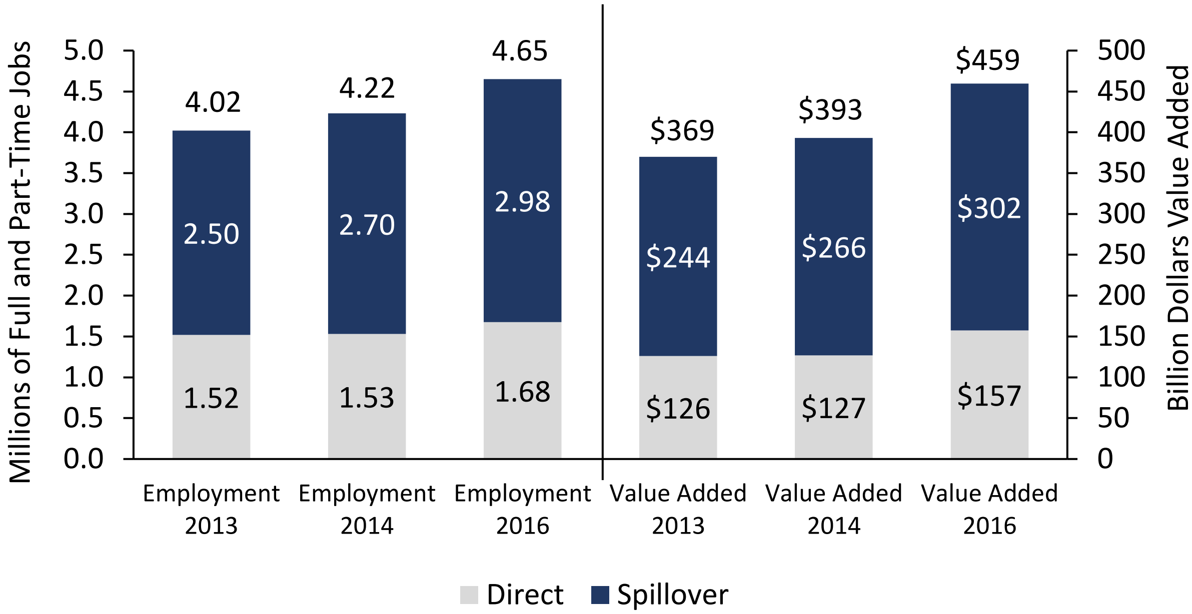


Figure 7: Biobased Products Economic Impacts Growth for 2013, 2014, and 2016 for Value Added and Employment.

Figure 8 illustrates how the value-added produced by the biobased sector is allocated across each state (using an approximated range), and Figure 9 shows the number of jobs that the biobased economy contributes to by state. An important conclusion from these figures is that the biobased sector impacts every state in the nation, and that its impact is not just confined to states where agriculture is the main industry. Although these figures are based on data from 2013, the most recent year for which this data was modeled at the state level, the geographic distribution of the economic impacts of the biobased industry is likely still similar.

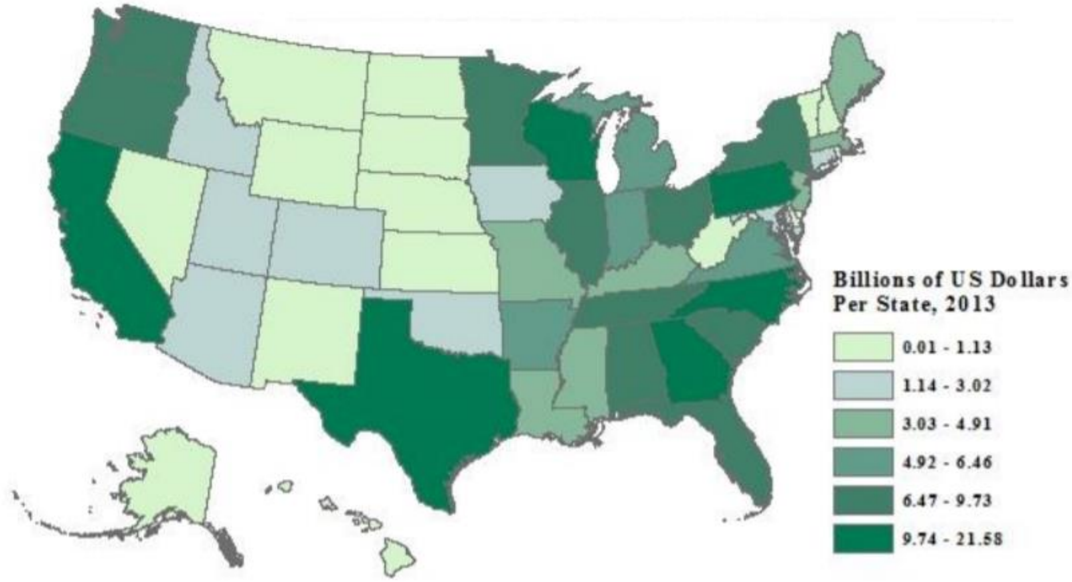


Figure 8: Direct Value Added Contributed by the Biobased Products Industry in Each State and the District of Columbia in 2013.[13]

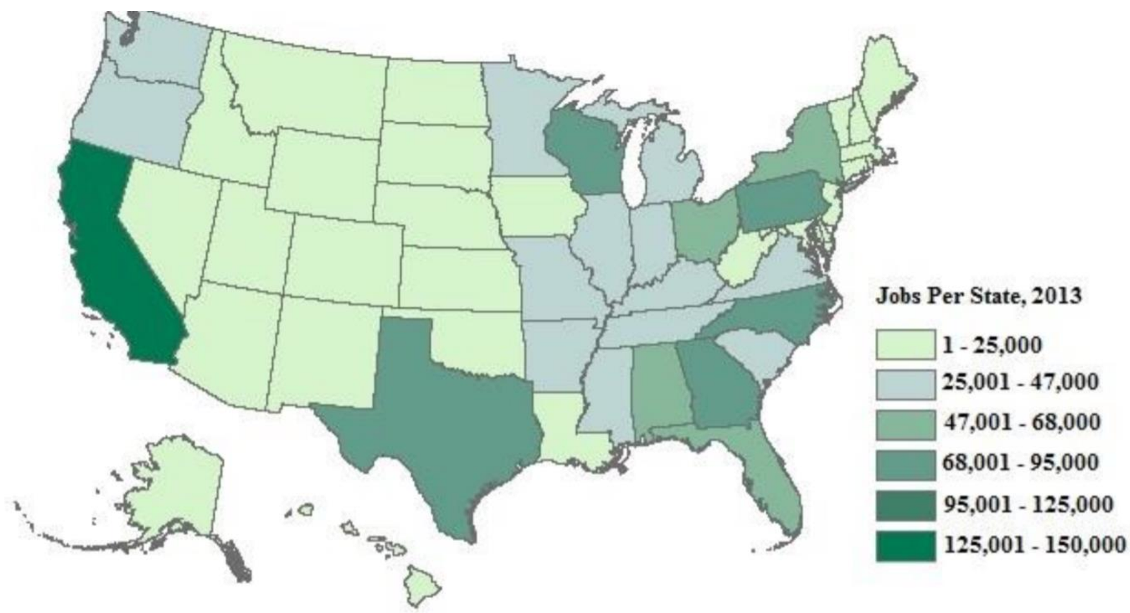


Figure 9: Direct Jobs Contributed by the Biobased Products Industry in Each State and the District of Columbia in 2013.[14]

[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, 2016. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf

[14] 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, 2016. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf

The top 10 states that contributed to the biobased products industry for the most recent data modeled at the state level (2013) are listed in Table 1.

Table 1: Top 10 States for Direct Value Added to the Biobased Products industry in 2013.[15]

Rank	State	Rank	Sate
1	California	6	Wisconsin
2	Georgia	7	Alabama
3	Texas	8	Tennessee
4	Pennsylvania	9	Ohio
5	North Carolina	10	South Carolina

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 sub-sector 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 North American Industry Classification System (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. However, the research team 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.

The next phase required the research team to develop an estimate for the biobased percentage of each sector. For example, what percentage do biobased chemicals comprise

[15] 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, 2016. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf

[16] Golden J.S. and Handfield R.B., "Why Biobased? Opportunities in the Emerging Bioeconomy," USDA BioPreferred® Program website, http://www.biopreferred.gov/BPResources/files/WhyBiobased.pdf, accessed April 2015.

of the total chemical sector? To accomplish this task, we analyzed the peer-reviewed literature; both domestic and international reports; literature related from industry and trade organizations; and market intelligence reports. We also conducted interviews of representatives from industry, non-governmental organizations (NGOs), academia, and the government. Table 2 provides the estimated percentage of each sector made up of biobased products (for example, the estimated percentage of the chemicals industry made up of biobased chemicals is four percent).

Table 2: Percentages of Biobased Products in Each Sector of the U.S. Economy in 2016.

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 Bio-based Chemicals, Biotech Support Service, 2015 (BSS)[20]
Enzymes	100	BCC Research Report (January 2011)[21]

[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. http://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), http://biotechsupportbase.com/buy-biotechnology-books-online/e-books-downloads/bio-based-chemicals/.
[21] BCC Research, "Enzymes in Industrial Applications: Global Markets," January 2011, https://www.bccresearch.com/market-research/biotechnology/enzymes-industrial-applications-bio030f.html.

Sector	Percent Biobased	Source
Plastic Packaging and Bottles	0.28	European Bioplastics, Institute for Bioplastics and Biocomposites, nova-Institute (2014)[22]

Note: Where conflicting percentages were presented, the research team elected to utilize the lower, more conservative estimates.

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

2.2.1 Agriculture and Forestry

The Support Activities category in Table 2 includes cotton ginning, soil testing, post-harvest activities for crops, timber valuation, forest pest control, and other support services for forestry as determined by the Census Bureau. The average figure of 14.4% for support activities across all sectors was derived based on the total support activities and the amount of output of corn, timber, and other products as a percentage of the total agricultural production used to create biobased products. We assumed all sectors utilized the same support services equally. Certain sub-sectors are worth noting here. In 2013, corn biorefineries processed 1.5 billion bushels of corn, the equivalent of about 10% of the U.S. corn crop.[23] The corn was used to produce starch (17%), sweeteners (53%), and ethanol (30%). About 2% of the entire corn crop was used to produce biobased products from starch. We have not included the amount of ethanol that was used to produce biobased products.

2.2.2 Biorefining

Biorefining accounts for approximately seven percent of the total refining capacity in the U.S. We 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 that are 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] estimated that 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 U.S. was 17,830,000 barrels per day, which is equivalent to approximately 6.508 billion barrels per year.

2.2.3 Textiles

About 51% of textiles, including cotton and rayon, are produced from biobased feedstocks. Cotton Inc. estimated that 75% of summer clothing and 60% of winter

[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.
[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.

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, with most of them being in retail sales. In 2012, textile manufacturing accounted for 148,100 jobs. Information regarding sectors that produce forest products, biobased chemicals, enzymes, and bioplastic bottles, and packaging is presented in greater detail later in this report.

[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/.

2.3 Agriculture and Forestry

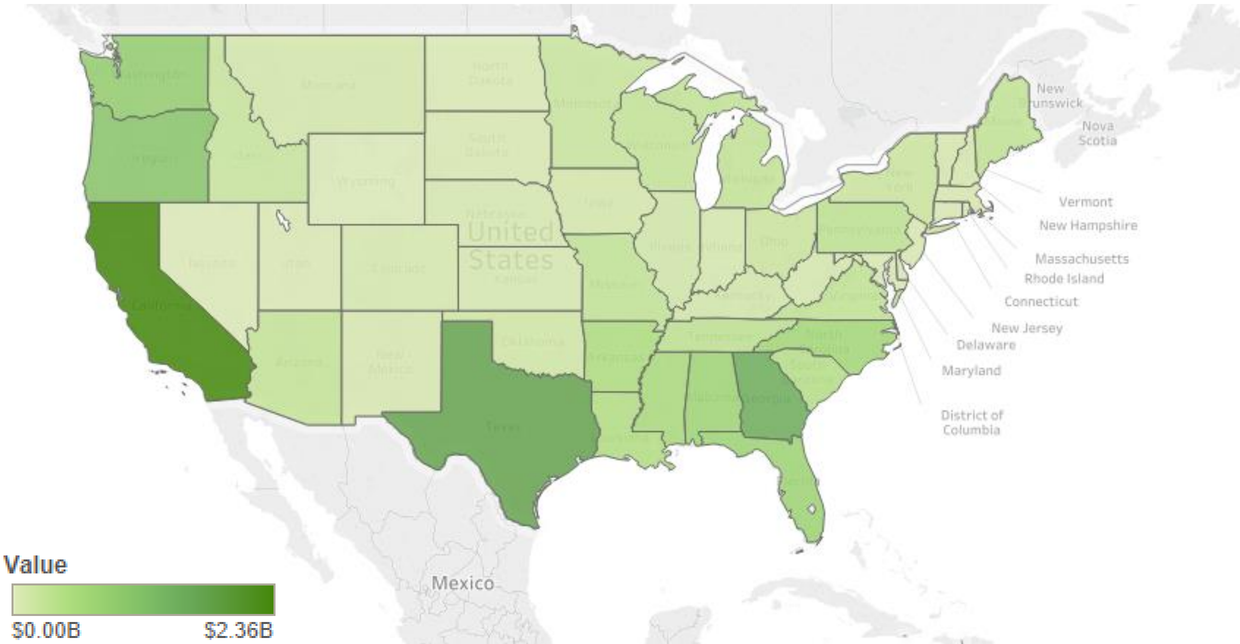


Figure 10: Total Value Added Contributed by the Agricultural Industry in Each State and the District of Columbia in 2013.

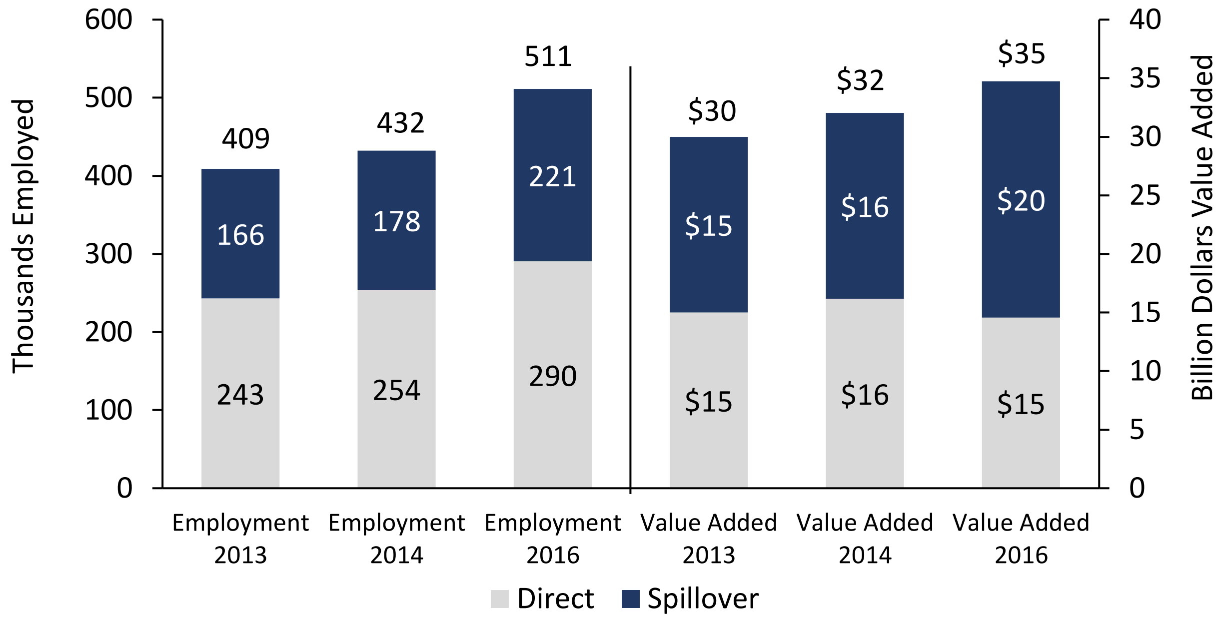


Figure 11: Agriculture's Contribution to Employment and Value Added in 2013, 2014 and 2016.

Approximately 2.1 million farms contribute to America's rural economy. About 99% of U.S. farms are operated by families, i.e., individuals, family partnerships, or family corporations, which, in many cases, are suppliers to companies, such as the major firms listed below. [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 2016: $35 billion
Exports value added to the U.S. Economy in 2016: $11.7 billion
Type SAM Economic Multiplier in 2016: 2.4

Employment Statistics
Total number of Americans employed due to industry activities in 2016: 511,000
Total number of Americans employed due to industry activities supporting exports in 2016: 152,000
Type SAM Employment Multiplier in 2016: 1.8

Table 3: Distribution of Direct Value Added and Employment by Agriculture and Forestry Sub-Sectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	129,000	$6,309,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	88,000	$3,300,000,000
8	111920	Cotton farming	52,000	$3,837,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	14,000	$788,000,000
2	111150	Grain farming – only corn included	6,000	$184,000,000
9	111930, 111991	Sugarcane and sugar beet farming	300	$23,000,000
1	11111	Oilseed farming	1,000	$114,000,000
		Totals	290,300	$14,555,000,000

[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/.

2.3.1 OVERVIEW

The Agriculture and Forestry sector is made up of three main subsectors, i.e., 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, i.e., 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% 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

2.3.2.1 Cotton Farming

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

Therefore, the industry is highly dependent on the conditions of the global market due to the very small amount of domestic demand. Figure 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 that revenue will stabilize over the next five-year period, with annual growth of a minimal 0.1%.

[29] "About the Forestry and Logging Subsector," U.S. Bureau of Labor Statistics, United States 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, United States 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

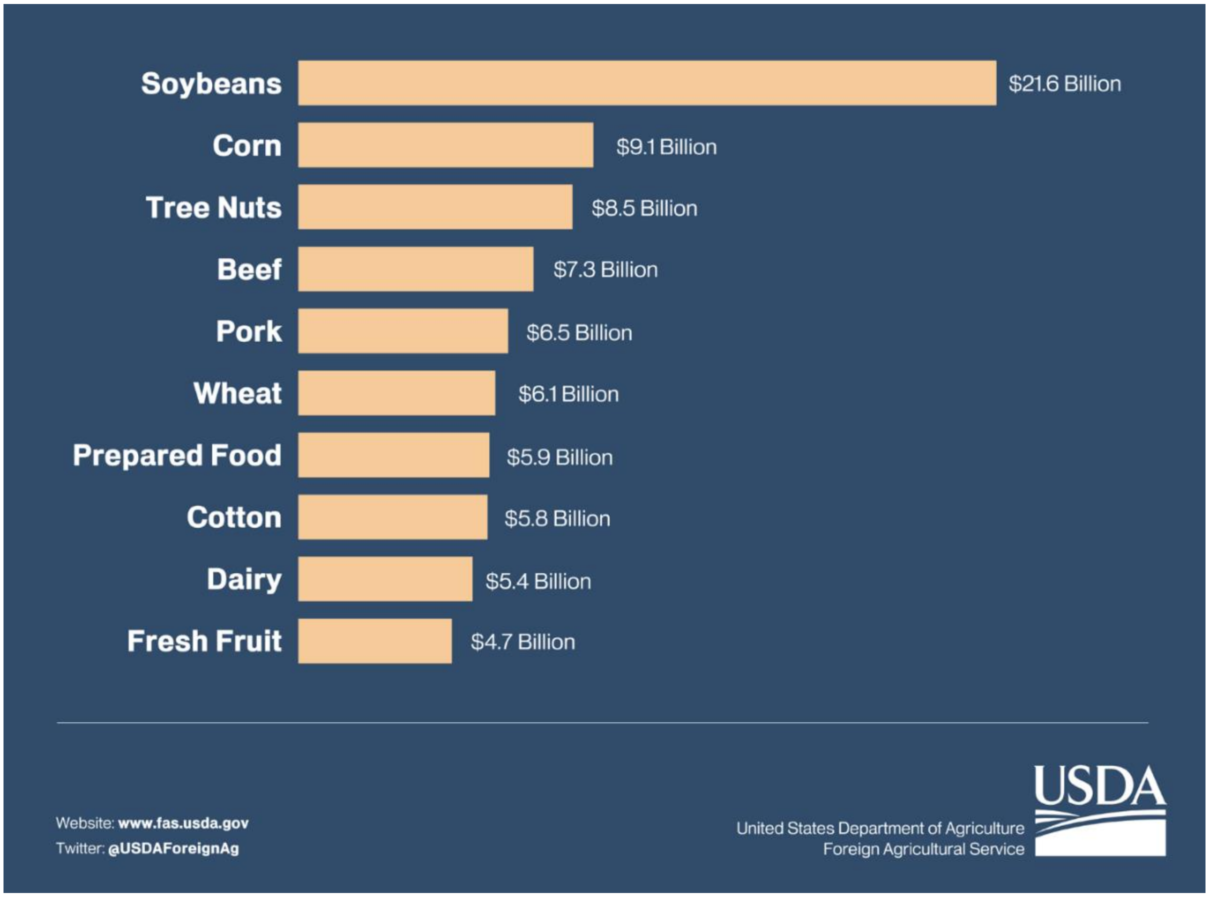


Figure 12: Top U.S. Agriculture Exports in 2017.[32]

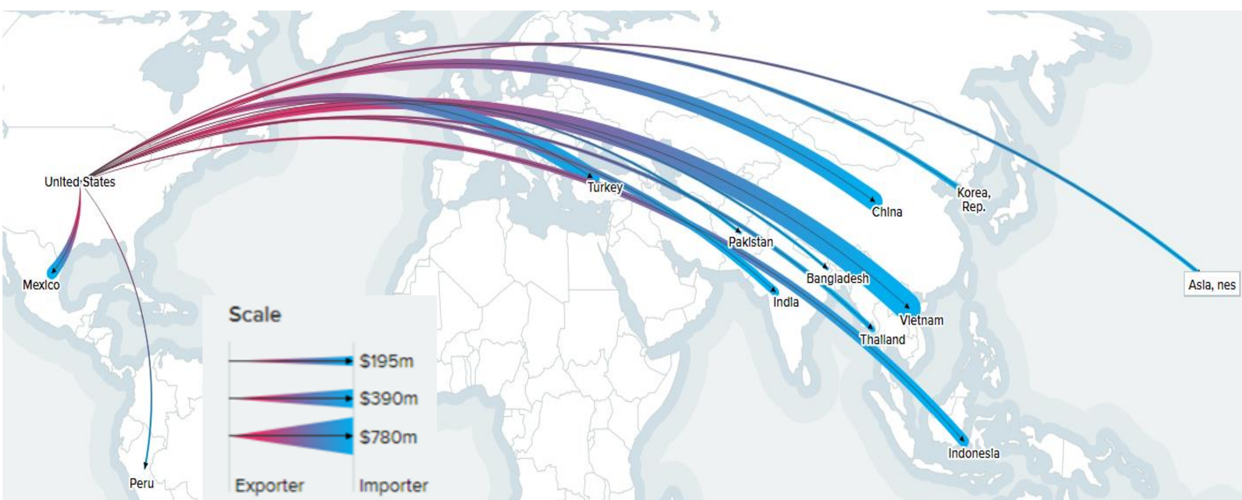


Figure 13: United States Cotton Export Flows.[33]

[32] "Top U.S. Agricultural Exports in 2017," USDA Foreign Agricultural Service website, accessed April 2018. https://www.fas.usda.gov/data/top-us-agricultural-exports-2017.

[33] ResourceTrade.Earth, Chatham House Resource Trade Database, accessed May 2017. https://resourcetrade.earth/data?year=2016&exporter=842&category=90&units=value.

2.3.2.2 Sugarcane Harvesting

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

2.3.2.3 Corn Farming

In the five years leading up to 2017, the entire corn industry sustained huge losses because demand was far surpassed by production due to bumper crops and favorable weather. Fig. 11 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 annualize rate of 1.1% over the five-year period from 2018 to 2022. However, export revenues over that same period are expected to increase at an annualized rate of 2.8%. 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.

2.3.2.4 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, e.g., corn, soybeans, and wheat. For this reason, industry revenue can vary extensively 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% 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 forecasted to grow at an annualized rate of 1.3%. The demand for high-quality vegetable oils from important foreign markets will boost exports.

2.3.3 FORESTRY AND LOGGING

2.3.3.1 Logging

During the past five years, the industry had moderate growth, mainly due to the growing strength 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%.

2.3.3.2 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 United States leads the world in the production of timber for industrial products, accounting for approximately 25% 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, and they were obtained from the pine forests in the southern United States. Currently, these products include rayon fabrics, filters, cosmetics, fragrances, pine oils, and many others.

2.3.3.3 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% over the next five-year period.

2.3.3.4 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 forecasted to decrease over the next five years, an increase in production is expected to boost the need for services. Thus, the revenue is expected to increase at an annualized rate of 0.7% over the next five-year period.

2.3.3.5 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. The 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: Cotton Incorporated

Cotton Incorporated is a nonprofit organization that aims to increase the demand for cotton by discovering new applications, increasing market share in existing product categories, and improving the overall profitability of growers. This nonprofit supports U.S. farmers and all producers of cotton globally.

Cotton LEADS cotton has been certified as a USDA Certified Biobased Product by the BioPreferred Program. The entire cotton plant (cotton fiber, cottonseeds, and cotton trash) can be utilized through a variety of applications. One of the principal components of the cotton plant is the fiber. Also called lint, the fiber is most often spun into yarn, 85% of which goes into apparel, and 10% of which goes into home textiles (e.g., sheets, towels, and pillowcases). The remaining 5% of the cotton fiber goes into nonwoven products, which include diapers, baby wipes, cosmetic puffs, and personal hygiene products. Cotton fiber is primarily made up of cellulose, which makes it a good source to make derivatives of cellulose, such as cellulose acetate and nitrocellulose. Pure cellulose acetate goes into a variety of products, including panels on televisions, screwdrivers, and the visors on motorcycle helmets. Nitrocellulose can be made into rocket propellants and smokeless gunpowder. Other derivatives of cellulose, such as cellulose gum, can also be used as the wicks of candles.

Cotton plants produce about 1.5 pounds of seed for every pound of fiber. The seeds are made up of a tough outer shell, called the hull, and a kernel, which is comprised of oil and protein. Through processing, the kernels are removed from the hulls and crushed, and the oil is extracted. The hulls and meal leftover from the extraction of the oil are commonly used as a feed supplement for dairy cattle. More recently, cottonseed is being used in the aquaculture industry as fish food. Additionally, the hulls are often incorporated in the mud used in drilling for oil. Another segment in which cotton seeds are used is the production of cottonseed oil, which is used primarily in restaurants and commercial food operations to fry foods. Because of its use in food, cotton is regulated as a food crop by the FDA. The potato chip manufacturer, Utz, uses cottonseed oil for many of its brands. One acre of plants will yield a harvest of around 320 pounds of cotton, which, in turn, can produce 40 gallons of oil, enough to produce 30,000 bags of single-serve potato chips.

In addition to the lint and the seed, there is the "trash." The term "trash" refers to the leaf and the bark that are included in the harvest but, in fact, are not at all trash" For a bale of cotton that weighs 480 pounds, 140 pounds, or around 30%, will be trash. The "trash" is separated in the cotton gin, and it is used in many products. Trash is used in garden mulch and as a commercial fertilizer, in composites, resins, and thermoplastic extruded decking boards, in erosion-control products, and it even is used to stuff archery targets. Research is being conducted to explore

opportunities to replace Styrofoam products, as well as the medium-density particle board that is used in shower stalls and bathtubs with products made with cotton trash.

Contribution of Cotton to the Biobased Economy

The U. S. is the third largest producer of cotton in the world, and, in 2017, it produced more than 20 million bales, which was about 16.5% of the estimated worldwide production of 121 million bales. Currently, the U.S. is the number one exporter of cotton, which is largely due to the shift in the textile manufacturing industry from the U.S. to China and Asia. Before 2000, the U.S. was a major consumer of cotton for use in textile mills, but it is now a net exporter due to the lack of domestic production in cotton mills. Currently, the U.S. uses about 4.5 million bales out of the 20 million bales produced annually. This usage represents a decrease from 12 million bales it used annually before 2000. Yarn manufacturing essentially has moved overseas as well, and, while some domestic apparel production is returning, 70% of the cotton produced by the United States is exported.

During the 1960s, cotton farmers began facing increased competition from the burgeoning petroleum-based fiber industry, i.e., the production of nylon and polyester. As a result, the market for synthetics is a strong predictor of the movement of cotton prices. In response, Cotton Incorporated was created in 1970 to support U.S. farmers and other producers of cotton globally. An important function of Cotton Incorporated is to provide market research on all dimensions of cotton, including developments in cotton production, cotton products, consumer-based metrics, and sustainability information. The Company also is focused on advertising and maintaining a presence in social media and television.

Apparel Products

Mark Messura, Senior Vice President of Global Supply Chain Marketing, is focused primarily on product innovation. Cotton Incorporated works with over 400 companies in the United States and with 1,500 companies worldwide. In collaboration with these major brands, retailers, manufacturers, and supply chain companies, Mr. Messura helps find innovative ways to convert fiber into product applications. Mr. Messura also encourages new brands and manufacturers to consider cotton as a key ingredient in their products.

Mr. Mesura notes that some of the major benefits of cotton over other materials in apparel include:

- Greater comfort against the skin
- Ease of care
- Versatility – can be used in many different apparel applications
- The price is competitive, and cotton can be used in many applications, including resistant or wicking finishes.

Nonwovens

Jan O’Regan, Director of Nonwovens Marketing, focuses on identifying non-apparel applications for cotton. Half of these applications are in non-spun technologies, and the other half is in staple fiber technologies. Ms. O’Regan notes that for non-spun technologies, cotton resin is fed into its various applications and melted. In staple fiber applications, chemical, mechanical, and thermal processes are used to make fabrics from fibers. In hydro-entangled technologies, the fibers are placed on a carded belt, and high pressure jets make them into fabric.

There are several emerging applications for cotton. Because cotton is a natural product, light weight, and recyclable, the automotive industry is particularly interested in its use. BMW is using reinforced cotton in the dashboards and door panels of its i3 model. Additionally, several companies are experimenting with using fiber reinforcements in bumpers, side panels, and body panels. Another emerging application for cotton is its use in 3D printing.

2.3.5 Case Study: Ford

During the course of this study, we interviewed one of Ford's scientists, Dr. Alper Kiziltas, to determine how different sustainable and alternative materials were being used and integrated into Ford's supply chain. Dr. Kiziltas has studied many biobased, sustainable, and alternative materials, including recycled and renewable materials, nanotechnology, and organic materials, such as cellulosic products from trees, electroconductive materials, and self-cleaning materials. Recently, Ford celebrated its tenth year of using biobased materials in its vehicles. In 2013, Ford initiated the use of cellulosic materials and polypropylene, and, in 2014, it started using soybean-based material in the armrest substrate. The Company is seeking to use biobased polypropylene materials in the door panels by combining cellulose and fibers to produce parts that weigh 5-10 pounds each. Research also is being conducted to produce long molecule glass combinations that can be used to develop new hybrid composites that can be used in door panels and substrates. Partnerships are underway with International Paper in this area.

Dr. Kiziltas emphasized that it is important to examine the drivers that caused scientists to begin exploring the use of natural fibers in Ford's vehicles. What drove this effort was Ford's mission to reduce its environmental footprint, improve the recyclability of products, and limit climate change, all while maintaining affordable production costs and lightweight construction. Dr. Kiziltas remarked that this mission motivated scientists to begin exploring the use of lightweight cellulosic materials in place of glass. These cellulosic materials can provide almost a 40% reduction in density for fillers, which results in significantly lighter products. Dr. Kiziltas went on to highlight the importance of considering the cost implications of using biobased materials, stating that the biobased material must be able to meet all of the product's performance requirements and must be cost-competitive.

Dr. Kiziltas noted that there are certainly some technical challenges in this market because many of the cellulosic materials (hydrophilic and polycarbonate mixes) have issues with processing and degradation at the high temperatures required in injection molding processes. Despite this, Dr. Kiziltas maintained that Ford scientists see the value of using sustainable materials, and they are constantly seeking to overcome the challenges associated with using cellulosic and other alternative materials.

Additionally, Dr. Kiziltas acknowledged that biobased materials are still a niche market, but he was confident that this market would grow. Some of the growth is being driven by End of Life regulations in Europe, as well as research ties with upstream suppliers to develop fibers for the automotive sector. Automotive designers also are becoming more familiar with biobased materials, and they recognize the benefits of their light weight. This is making it more acceptable to replace metals with sustainable, fiber-based materials, thereby eliminating the need to always use high strength materials and creating a viable market for additional fiber and sustainable composite materials. Also, there is a need to eliminate the knowledge gap and change the mindset towards biobased products in the upstream supplier communities. After companies gain additional experience with these materials, they will find ways to efficiently design them into their products. Surprisingly, the interest in these materials is coming from management as well as through supplier-led (bottom-up) innovation promoted by purchasing teams.

To date, Ford has replaced 12-15% of its plastic-based applications with biobased and fiber-based materials, resulting in the replacement of approximately 400 pounds of plastics in medium-sized vehicles. While there are no specific targets for the use of biobased materials, the amount of these materials in new vehicles has increased dramatically in response to regulations as well as the interest shown by consumers. Much of what Ford has done was decided and implemented by Ford's management based on its emphasis on using these lightweight materials in its vehicles. If the government were to create credits or other financial incentives for using biobased materials, this would likely push more suppliers and original equipment manufacturers (OEMs) to use more green materials. As academic engineering programs graduate BS, MS, and Ph.D. engineers who are motivated to expand the use of renewable materials in vehicles, Ford expects the use of biobased materials will increase.

2.3.6 Case Study: Carolina Nonwovens

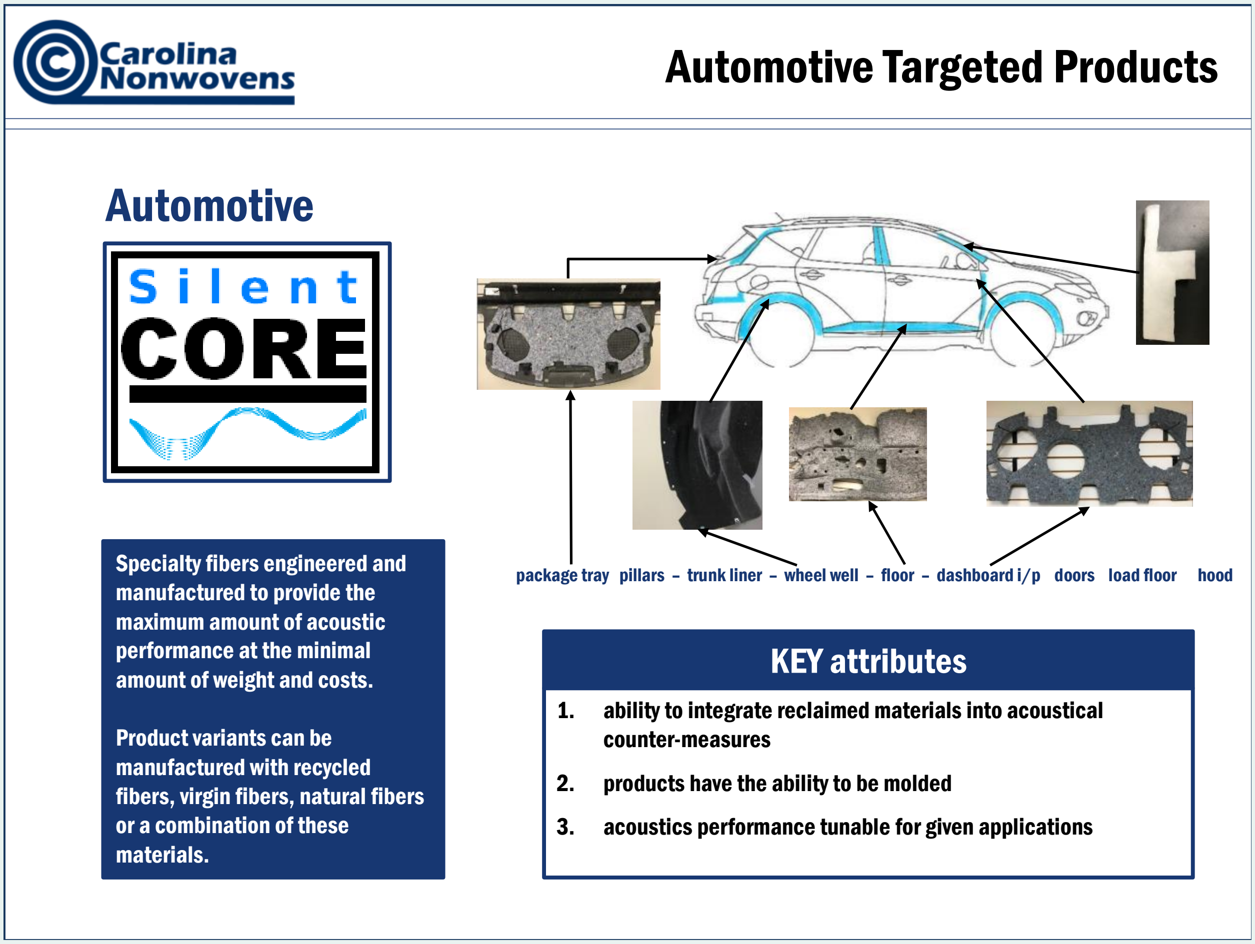
Companies such as Ford are not only exploring the use of biobased products in their own production processes, but they are also asking their suppliers to do so as well. For example, when Ford uses biobased fiber, this increases the demand for soybean seeds from Davenport Seed Company, located in Eastern North Carolina. These seeds are sold to BASF, which uses the seeds to manufacture and sell complete agricultural solutions to soybean farmers. Then, the farmers sell their crops to producers such as Jim Chestnut, who is the CEO of National Spinning Company in North Carolina. National Spinning sells several products, including the undercoating fiber produced from soy that is sold to Nitto Tire and International Automotive Components Group, both of which are major suppliers of Ford.

One of Ford's key upstream suppliers is Carolina Nonwovens, which is located in Hickory, NC. This company specializes in the manufacture of airlaid nonwoven materials, some of which are used in the automotive industry. The nonwoven materials manufactured by Carolina Nonwovens can be used in a variety of applications, including acoustical counter-measure, thermal counter-measure, bedding, construction, and composite media. Carolina Nonwoven's largest market is the automotive sector, which includes Nissan, BMW, Toyota, and Ford.

Carolina Nonwovens' products can be manufactured with recycled fibers, virgin fibers, natural fibers, or combinations of all three, but most of the Company's products are made from recycled raw materials. The manufacturing process re-uses fibers from manufacturing processes that produce waste from internal edge trim, die-cut part, and other forms of post-industrial waste (e.g., fiber from the manufacture of carpet and apparel) and post-consumer fiber (e.g., recycled denim or apparel). This recycled waste material is known as Moldable Synthetic Shoddy and is used extensively by customers in both the automotive market and the appliance market (e.g., Bosch dishwashers). The material can be molded to fit product specifications and requirements, and it is being used increasingly in a variety of applications in Ford vehicles.

Natural fibers that are used in the Company's nonwoven materials include cotton, kenaf, and jute, while recycled materials feedstocks primarily include denim, T-shirts, and sweatshirts. Goodwill is Carolina Nonwovens' largest supplier for recycled material. Approximately 65-70% of all material used in the facility is recycled, and about 20% of the material is virgin material. The remainder is the binder used to hold the products together (currently not available as a recycled product). Nonwoven products can be molded, trimmed, and cut to fit specific size specifications, and the scraps and trimmings created from this process are collected and sent through the manufacturing process again. There is no limit to the number of times the material can be re-used.

It is important to note that the nonwovens industry is almost import resistant due to the lightweight nature of the finished products. The challenge with textile markets is that recycled materials habitually have been more expensive than virgin materials. Thus, given the recent advances in technology and manufacturing processes, Carolina Nonwovens is actively seeking to change the impression that recycled materials are more expensive materials. It is apparent that companies such as Carolina Nonwovens can help differentiate the market when material is used that cannot be used in other applications. That is why Carolina Nonwovens considers itself to be a sustainable company given its utilization of recycled materials. Sustainability is high on the Company's agenda and is an obvious part of its profile, and it is aware that there also are significant after-market sustainability effects. For instance, the light weight of the noise-reduction materials used in making automobiles helps lower their total weight, and this, in turn, provides the advantage of enhanced mileage per gallon of fuel used. In addition to these advantages, Carolina Nonwovens is continuing to seek new applications of its recycled, non-woven materials in multiple industries.



2.3.7 Case Study: Reebok

Reebok is an “American-inspired global brand” with a deep fitness heritage and the mission to design and create the best gear and experiences for athletes and others interested in fitness. Reebok strives to inspire people to be their absolute best – physically, mentally, and socially.

Mike Andrews, Reebok’s Development Footwear Project Leader, is committed to identifying new materials to produce shoes that provide superior performance for Reebok’s customers. When he started working for Reebok 22 years ago, he worked in 3D Printing, then moved into product development, and later became Reebok's Project Leader for the "Advanced Development for the Future" program. Projects in this program have a three-to-five year planning horizon, and it operates within Reebok to explore new technologies.

Mr. Andrews said that his boss, the Vice President of Reebok's Development Group, challenged him to work on a "sustainable shoe." Mr. Andrews said that, initially, he was fairly confident in his knowledge and understanding of the biobased plastics industry and sustainability initiatives that were being pursued at the municipal and commercial levels. However, he added that he quickly learned how little he really knew. As a result, he began to study the available information so that he could understand the terminology, including the correct meanings of terms, such as recycled, biobased, biodegradable, and compostable. This led to an ongoing effort to research new materials for Reebok's shoes that would meet emerging goals for sustainability.

Mr. Andrews shared the approach he had taken over time, noting that his initial, admittedly lofty, goal was to develop a fully-compostable, and fully-biobased performance running shoe. Mr. Andrews indicated that he was interested in developing a sustainable shoe that looked the same as any shoe made from petroleum-based materials and had all of the same performance capabilities, aesthetics, and cost as any other shoe on the market. The only difference would be that the shoe also happened to be biobased, compostable, or both. Mr. Andrews began to experiment with biobased materials to see what might work. Mr. Andrews commented that he found it interesting that a lot of the big manufacturers did not see the profit potential in using biobased materials, and consequently, these manufacturers were not partnering with the biobased products industry. Conversely, he found that many smaller companies were motivated by a vision for what they wanted the industry to be, and therefore, he began working with these companies who were willing to support the biobased materials market at its early stages of development.

Mr. Andrews emphasized that the biobased plastics industry was nowhere near maturity, as the overall volume of biobased resin sold was not high enough to cover the cost of the investments required to produce the resin. But as more companies switch over to biobased resins and experiment with alternative materials they may never have considered in the past, the volume of products using these resins will grow. As an example, Mr. Andrews pointed to the areas of disposable packaging, forks, cups, and spoons. As the quantity of products sold increases, manufacturers will be able to lower the cost of the resin.

Mr. Andrews and the Development Footwear Project team began to develop a biobased shoe. Mr. Andrews noted that one of the key factors in developing the shoe was that it have the same properties as and be at least functionally equivalent to Reebok's existing shoes that were made of ethylene-vinyl acetate (EVA), rubber, and polyester. To that end, Reebok sought materials derived from sustainable sources that would provide the same level of performance and aesthetics and that would also have the ability to compost at the end of their useful life.

Mr. Andrews explained that he felt confident that he could strip away the layers of the "upper" (the top of the shoe) and use natural cellulosic materials on the "lower" sole to provide performance outcomes similar to Reebok's existing shoes. The sole material of the biobased shoe consisted of EVA foam and styrene-butadiene rubber (SBR) rubber. In shoe construction, the midsole provides the cushioning foam layer between the outsole (which provides traction and abrasion so the shoe doesn't wear out) and the upper. The development team focused on taking the shoe and breaking it down into the components that remained outside of the upper and the outsole, and replacing the remaining components with materials that fit into the project goal.

Mr. Andrews went on to emphasize that the lack of existing elastomeric foams with a high biobased content or which could be considered compostable was a significant obstacle. The development team is continuing to work on that part of the shoe to create a foam that meets their goals. This is an on-going effort that the team is continuing to work on. As the team worked through these obstacles, Mr. Andrews explained that he found some good suppliers that could help them create a market-ready product that did not meet all of their target objectives, but met some of them. This compromise allowed the team to develop some prototype shoes, which eventually led to the current model, which is a USDA Certified Biobased Product containing 75% biobased content.

The current version of the shoe has a sole that is produced from a biobased thermoplastic polyurethane (TPU) material derived from corn, while the insole border is a biobased polyurethane. The upper and laces are 100% cotton, which also are biobased materials. The biobased materials used on the shoe also include two patches of vegetable-tanned leather on the tongue and the heel, and even the lace aglets and lace tips are cellulose acetate. Since the cup, sole, and bottom represent two-thirds of the weight the shoe, their biobased content met the bulk of the requirement for certification through the USDA BioPreferred Program. The shoe launched in early 2018, and Mr. Andrews noted that they are continuing to work on other shoes that are biobased and fully compostable.

Reebok is proud to have produced the first commercial athletic shoe that has achieved certification through the USDA BioPreferred Program, and the Company continues to explore other materials that can be used for this purpose.

Mr. Andrews emphasized that Reebok is truly in the early stages of the journey to explore alternative biobased materials in the consumer market. Mr. Andrews also noted that, unfortunately, many consumers are not yet aware of what biobased really means, but it is his sincere hope that others will see what Reebok has achieved and will be motivated to begin developing biobased products as well. As the biobased products industry expands, so too will the volume of biobased plastics that replace traditional petroleum-based plastic materials, such as TPU.

2.4 Biorefining

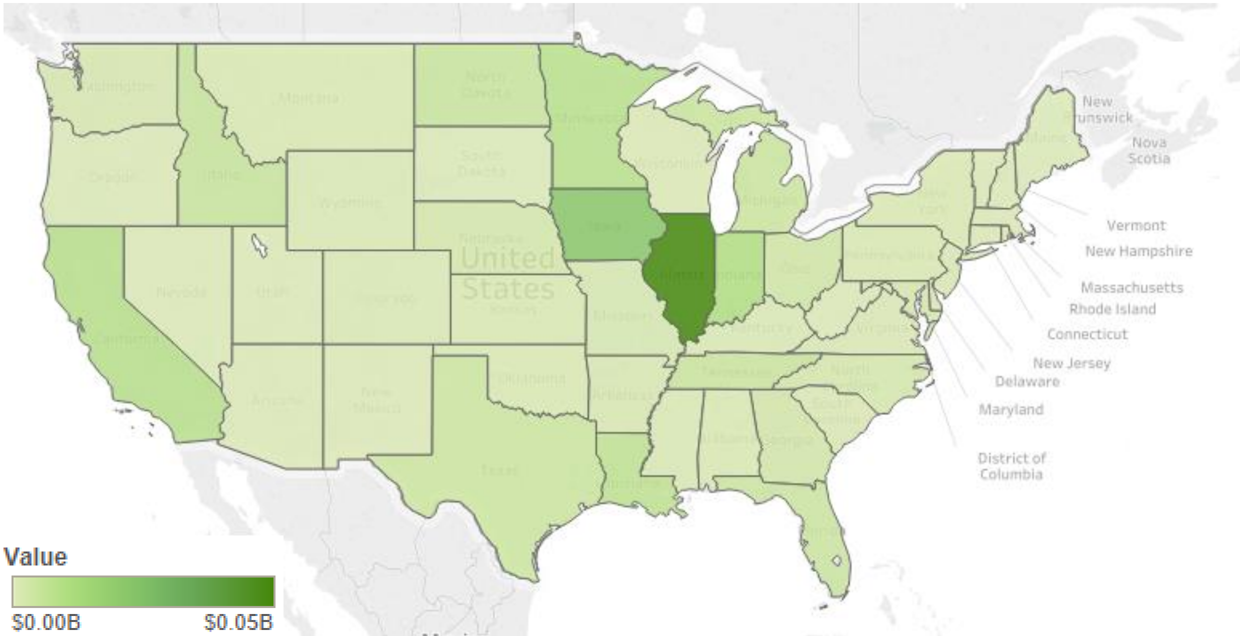


Figure 14: Total Value Added Contributed by the Biorefining Industry in Each State and the District of Columbia in 2013.

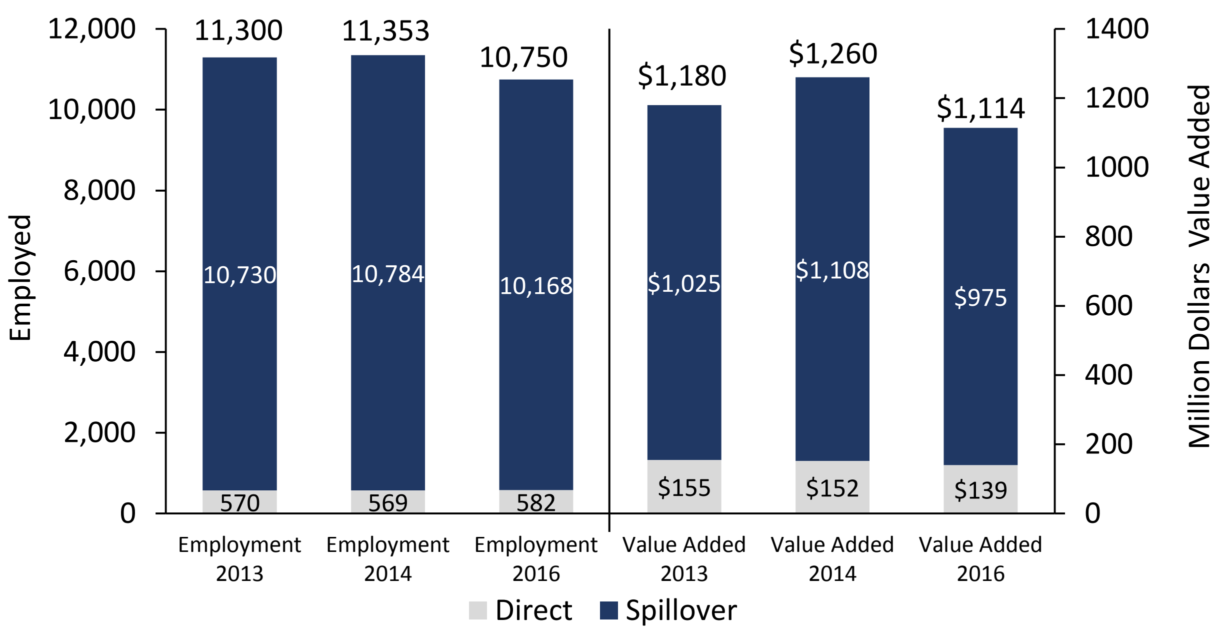


Figure 15: Biorefining's Contribution to Employment and Value Added in 2013, 2014, and 2016.

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.[34]

Major U.S.-Based Firms[35]
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 2016:
$1.1 billion
Value added to the U.S. Economy by exports in 2016: $172 million
Type SAM Multiplier: 8.0 in 2016

Employment Statistics
Total number of Americans employed due to biobased industry activities in 2016: 10,750
Total number of Americans employed due to industry activities supporting exports of biobased products in 2016: 1,600
SAM Employment Multiplier: 18.5 in 2016

Table 4: Distribution of Direct Value Added and Employment by Biorefining Sub-Sectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
70	311221	Wet corn milling	257	$80,000,000
74	311313	Beet sugar manufacturing	126	$18,000,000
75	311311, 311312	Sugarcane mills and refining	106	$24,000,000
71	311222, 311223	Soybean and other oilseed processing	55	$11,000,000
72	311225	Fats and oils refining and blending	38	$5,000,000
		Totals	582	$139,000,000

2.4.1 Biorefining Industry Report

2.4.1.1 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%. 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

[34] 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.
[35] Forbes, The World's Biggest Public Companies, Forbes website, accessed April 2015. http://www.forbes.com/global2000/list/.

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.[36] 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.[37]

2.4.2 Case study: Goodyear

Beyond obvious differences in style, tread, and price, many consumers may not think deeply about their cars' tires. Tires are generally produced from rubber and oil, with other components including steel and casing. The majority of the rubber used is a petroleum-based synthetic rubber. However, this trend is about to undergo a significant change based on a recent innovation produced by the research and development team at Goodyear.

This new technology is due, in part, to the work of organic chemist Robert Woloszynek, who has been working at Goodyear for just over a decade. Currently, Dr. Woloszynek is the Chief Engineer of Polymer Science and Technology, where his focus is on emerging technology in the areas of polymers and tire compounding. His work in this area brought the possibility of using soybean oil to his attention.

In our interview with Dr. Woloszynek, he stated that, initially, this project was not focused on trying to identify biobased materials. Instead, he indicated Goodyear is always looking at alternative materials – biobased or not. Consequently, the Company had been looking at soybean oil as a potential raw material input for tires for some time. However, the Company's interest peaked in 2011 while they were discussing another research project with Ford employees. The Ford employees mentioned that they had been collaborating with the United Soybean Board (USB), which prompted Goodyear to reach out to the USB.

Dr. Woloszynek stated that they began meeting with the USB in 2011, and they were invited to attend technical panel meetings where they could be introduced to people working with soybean

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

[37] 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.

oil. This accelerated the development of Goodyear's tire technology as the partnership grew through the active support of the USB. According to Dr. Woloszynek, the development project has accelerated within the past two years.

One of the key properties of soybean oil is that it has a much lower glass transition temperature compared to petroleum-based oil. Dr. Woloszynek and his team were particularly interested in leveraging this property, and, based on earlier studies, they began exploring the compatibility of different oils with the natural and synthetic rubber used in tires. In the process, they discovered that the compatibility of soybean oil and rubber was significantly better compared to that of petroleum-based oil, which makes it much easier to process the rubber when manufacturing tires. This compatibility created a processing benefit, and, because of the lower transition temperature, Goodyear was able to use soybean oil to create a better all-weather tire.

In manufacturing tires, one of the biggest challenges involves what is considered an age-old tradeoff: balancing traction on wet roads versus balancing traction on snow-covered roads. Tires designed for use in the winter perform exceptionally well due to their traction during those months, but they wear more quickly than a high-performance summer tire. Thus, summer tires last longer, but they are not as pliable as winter tires in cold temperatures, and they do not provide reliable traction in snow. Usually the compounds in tires that perform well under wet conditions do not perform well in snow and ice. However, by using soybean oil in the rubber mix, Goodyear leveraged the oil to render the tires more pliable at lower temperatures, which improved their performance in cold weather while maintaining their good performance in wet and warmer conditions. This was a key performance concern that had never been fully addressed in the past. Goodyear found that soybean oil could improve the flexibility of tires at low temperatures, simultaneously allowing the rubber to remain pliable in cold weather and to provide enhanced traction in rain and snow.

Following extensive analysis and road testing, this new technology is now being used in two new Goodyear tires, i.e., the Assurance WeatherReady and the Eagle Enforcer All Weather. At the 2018 Tire Technology Expo in Hannover, Germany, the Company was recognized for this achievement and was awarded the prestigious "Tire Technology International Award for Innovation and Excellence"[38] in the category of "Environmental Achievement of the Year."

[38] "2018 Awards Winners," Tire Technology Expo website, accessed April 2018. http://www.tiretechnology-expo.com/en/awards.php.

In a press release, Chris Helsel, Goodyear's Chief Technology Officer, stated, "Our work with the United Soybean Board presented a unique challenge and opportunity for our material scientists and tire engineers to employ soybean oil in the development of superior performing tires… It is exciting to see that work payoff with commercially successful products, and an honor to be recognized by the industry for the environmental achievement."[39]

The Assurance WeatherReady is a broad-based replacement tire for passenger cars; it is a size that is used in 77% of all cars, minivans, and non-commercial trucks. The Eagle Enforcer All Weather tire is designed specifically for police pursuit vehicles, and it meets the all-season, all-weather, and high performance requirements that law enforcement vehicles must have.

39 "Goodyear Soybean Oil Technology Wins 'Environmental Achievement of the Year' Award," Goodyear Corporate website, February 22, 2018. https://corporate.goodyear.com/en-US/media/news/goodyear-soybean-oil-technology-wins-environmental-achievement-of-the-year-award.html.

On average, a typical tire has about 8% of soybean oil by weight, and this oil replaces petroleum-based oil. The additional components of a tire include rubber, steel, and other reinforcements. In the Assurance WeatherReady tire, Goodyear replaced 100% of the petroleum-based oil in the tire tread and reduced the total volume of petroleum-based oil used in making the tire by 60%. The soybean oil used in the Assurance WeatherReady tire alone requires the use of approximately 40,000 – 60,000 bushels of soybeans in the initial application. This figure will continue to increase as the use of soybean oil in other tires becomes commonplace.

Goodyear is leveraging the soybean oil produced at its chemical plant in Beaumont, TX in two forms: as an additive and as a tire polymer that goes into the rubber compound. Although soybean oil has been leveraged primarily for its performance in wet and winter conditions, Goodyear is considering other process improvements, such as a polymer extender. Some of these specifications call for U.S. commodity grade soybean oil, as opposed to a specialized blend, such as the high oleic material being developed by the USB.

Goodyear also is exploring the use of other biobased materials, including rice husk ash. Each year, more than 700 million tons of rice are harvested worldwide, and disposing of the rice husks is an environmental challenge. As a result, the husks are often burned to generate electricity and reduce the amount of waste shipped to landfills, and the resulting ash consists of mainly silica. While this ash has been converted to silica for several years, only recently was the silica of high enough quality for use in tires. The silica can be used as a reinforcing agent in tire tread compounds, and it has the performance benefit of reducing rolling resistance, which improves the fuel economy of a vehicle and can also have a positive impact on the traction of tires on wet surfaces.

In both of these cases, the decision to use a biobased material was made based on the performance benefits, not as a "green" solution. Goodyear made the decision to use soybean oil because it is a unique material that could be used to meet a challenging performance goal. Of course the benefit of using a sustainable material is important, but this provides an important lesson for other biobased innovation pioneers, i.e., success is defined primarily by the improved performance delivered by the material. Product developers must identify a technical gap that the material can fill, and it must be possible to produce the material in such a way that competitive cost requirements are met. In the future, Goodyear will use the same criterion (i.e., delivery of the desired performance) as it seeks other applications for soybean oil in its other tire brands.

As noted by Graham Heeps, editor of *Tire Technology International* in Goodyear's Press Release, "Goodyear's innovative industrialization of soybean oil technology proves that research and development in sustainable materials can benefit not only the environment, but also tire performance. I believe that this type of 'win-win' innovation will increasingly become the norm, rather than the exception, in the tire industry of the future."[40]

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[40] "Goodyear Soybean Oil Technology Wins 'Environmental Achievement of the Year' Award," Goodyear Corporate website, February 22, 2018. https://corporate.goodyear.com/en-US/media/news/goodyear-soybean-oil-technology-wins-environmental-achievement-of-the-year-award.html.

2.5 Biobased Chemicals

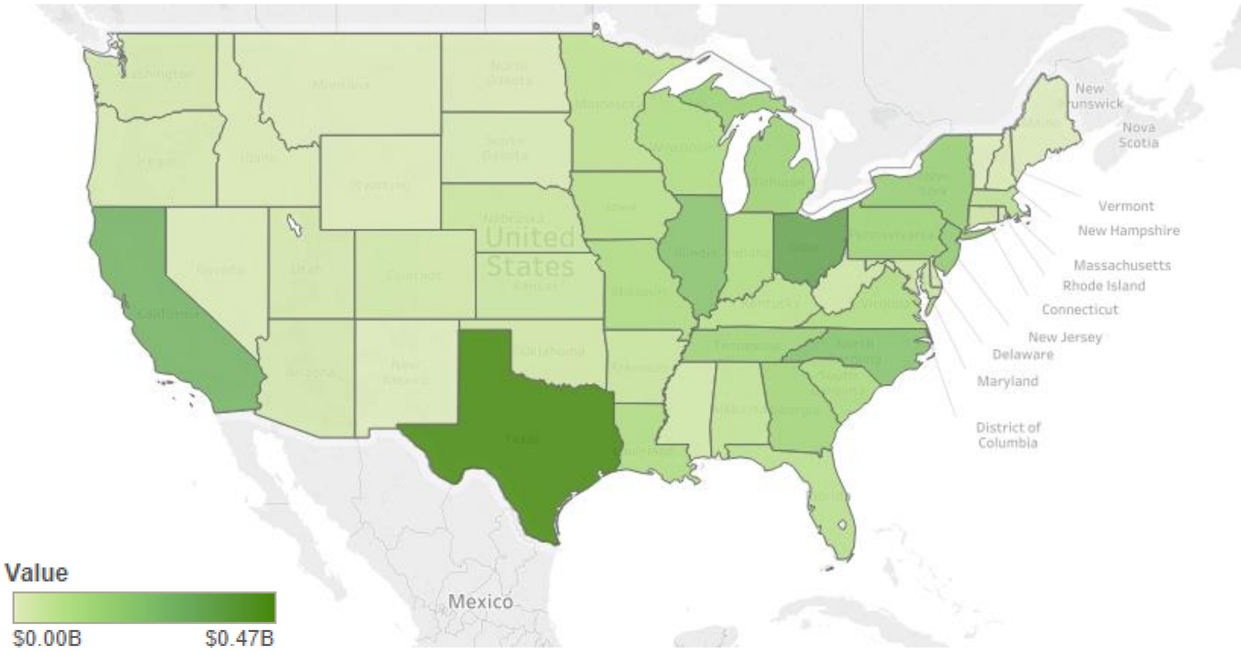

Figure 16: Total Value Added Contributed by the Biobased Chemical Industry in Each State and the District of Columbia in 2013.

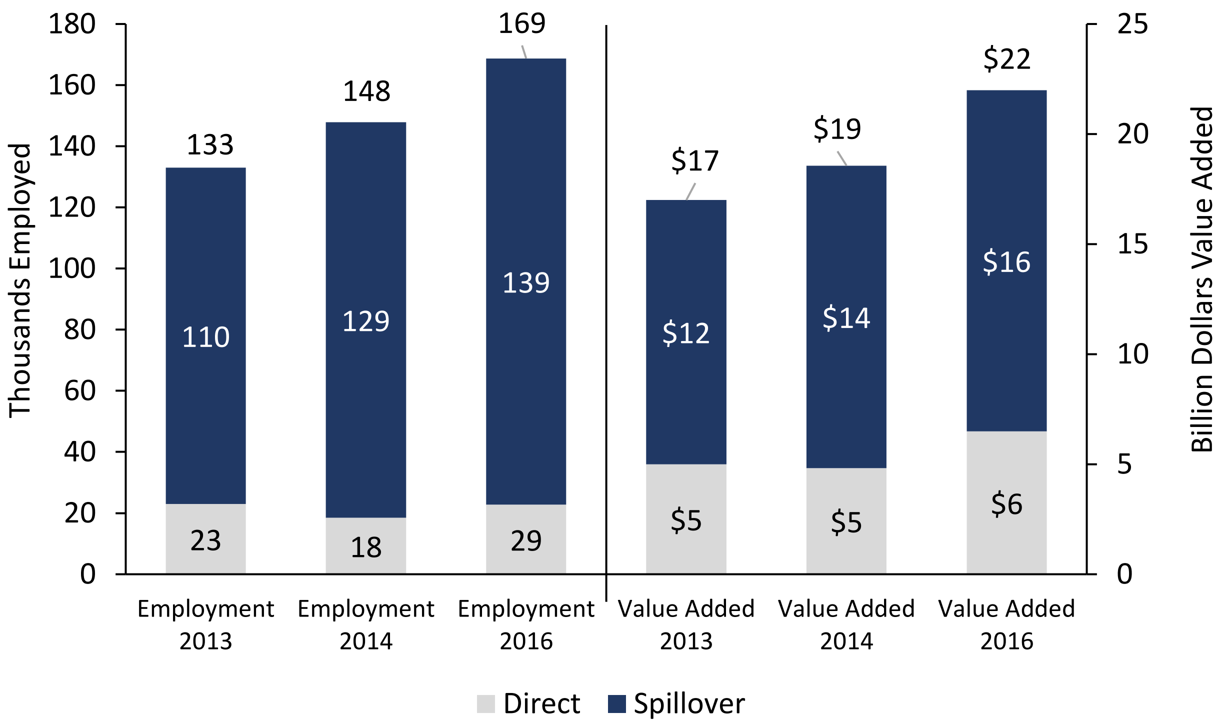

Figure 17: Biochemical Contribution to Employment and Value Added in 2013, 2014, and 2016.

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%. In 2017 alone, it was predicted that revenue would increase by 5.8%. Increased demand from downstream consumers, overall part of an expanding economy, signals a return to increased revenue and profits for the industry.[41]

Major U.S.-Based Firms[42]
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 2016 $22 billion
Exports value added to the U.S. Economy in 2016: 4.6 billion
Type SAM Value Added Economic Multiplier in 2013: 3.40

Employment Statistics
Total number of Americans employed due to industry activities in 2016: 169,000
Total number of Americans employed due to industry activities supporting exports in 2016: 35,000
Type SAM Employment Multiplier in 2016: 5.7

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

Table 5: Distribution of Direct Value Added and Employment by Biobased Chemicals Sub-Sectors.

IMPLAN Code	NAICS Code	Description	Employment	Value Added
196	32621	Tire manufacturing	2,640	$317,000,000
182	325620	Toilet preparation manufacturing[43]	2,800	$1,203,000,000
198	32629	Other rubber product manufacturing	2,860	$295,000,000
166	325211	Plastics material and resin manufacturing	2,790	$762,000,000
165	32519	Other basic organic chemical manufacturing	2,510	$552,000,000
177	325510	Paint and coating manufacturing	2,180	$509,000,000
187	325998	Other miscellaneous chemical product manufacturing	2,020	$393,000,000
193	326150	Urethane and other foam product (except polystyrene) manufacturing	1,870	$190,000,000
192	326140	Polystyrene foam product manufacturing	1,620	$175,000,000
168	32522	Artificial and synthetic fibers and filaments manufacturing	1,150	$187,000,000
179	325611	Soap and other detergent manufacturing	1,410	$739,000,000
197	326220	Rubber and plastics hoses and belting manufacturing	1,230	$127,000,000
180	325612	Polish and other sanitation goods manufacturing	1,180	$390,000,000
178	325520	Adhesive manufacturing	1,120	$220,000,000
185	325991	Custom compounding of purchased resins	910	$154,000,000
186	325992	Photographic film and chemical manufacturing	560	$116,000,000
183	325910	Printing ink manufacturing	410	$70,000,000
181	325613	Surface active agent manufacturing	200	$86,000,000
		Totals	29,460	6,485,000,000

2.5.1 Biochemicals Industry Report

2.5.1.1 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, we have covered the

[43] 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.

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%. It was predicted that revenue would increase by 5.8% in 2017 alone, and early indicators imply this will be the case. Increased demand from downstream consumers signals a return to increased revenue and profits for the industry.[44]

Consumer spending and manufacturing have a direct effect on chemical demand since 96% 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 also is important to chemical manufacturing in that it is a key supplier to the industry and also is 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 the biochemical industry and invest in it.

2.5.1.2 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%. Exports, during the same period, are expected to increase by 0.4%.

[44] IBIS report

2.5.1.3 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%. This increase is expected because of a healthier economy, specifically a strong construction market and more disposable income.

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

2.5.1.5 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 to create a new market that relies on biobased products. As companies in the U.S. expand their reach globally, exports are expected to increase by 4.6% in the period between 2018 and 2022, while overall revenue is expected to have the very modest growth of 0.6%.

2.5.1.6 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%. Exports also are set to decrease by 0.9% due to the increasing competition from foreign producers. We estimate that biobased plastic production in the United States was approximately 0.3% of the total annual production of plastic, and we estimate that the entire chemical sector was 4% biobased chemicals.[45] Estimates of the future penetration of the market by commodity chemicals by 2025 vary from as little as 6% to 10% to as much as 45-50% for specialty and fine chemicals.[46, 47]

[45] BCC Research, "Biorefinery Applications: Global Markets," March 2014, p. 118.
[46] Bachmann, R. (2003), Cygnus Business Consulting and Research.
[47] 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: PLASTICS Bioplastics Division

The Plastic Industry Association's (PLASTICS) Bioplastics Division was established in 2007, and it currently has 22 members around the world, including BASF, Braskem America, the Coca-Cola Company, Deere & Company, DowDuPont, Eastman Chemical, PepsiCo, and PolyOne Corporation. The Plastics Industry Association is expanding its reach into the world of biobased products in response to several factors, including 1) regulations, such as those in the EU, that are encouraging movement toward sustainable products, 2) replacement of plastic by innovative new materials in many sectors, and 3) increased demand for biobased plastics created by increasing consumer awareness of compostability and the damage that plastic does to the oceans.

Our team had discussions with Patrick Krieger, who has worked for PLASTICS for three years. Mr. Krieger was involved in developing PLASTICS's Plastics Market Watch, which was released in 2018.[48] PLASTICS represents the entire plastic industry, including distributors, manufacturers, and plastic equipment manufacturers. The Bioplastics Division is a small segment of the PLASTICS that addresses bioplastics issues with the goals of providing education concerning bioplastics and their uses, collaborating on behalf of the industry, and promoting growth.

The Bioplastics Division has a goal of improving customers' knowledge and understanding of the subject. Recently, PLASTICS surveyed 1,000 U.S. consumers in January 2018, and 31% of them were still not at all familiar with bioplastics, which PLASTICS defines as a type of plastic that either is made from biobased materials, such as sugarcane and cornstarch, or is biodegradable. About 32% of the consumers were "familiar" or "somewhat familiar," with bioplastics, which was an improvement from a similar survey in 2016 in which only 27% of U.S. consumers knew about bioplastics.[49]

The first bioplastics were developed from traditional agricultural resources, such as corn, sugarcane, or soybeans. The second generation bioplastics that currently are beginning to be

[48] "Plastics Market Watch," Plastics Industry Association website, accessed July 2018. http://www.plasticsindustry.org/membership/resources-members/reports/plastics-market-watch.
[49] "Plastics Market Watch," Plastics Industry Association website, accessed July 2018. http://www.plasticsindustry.org/membership/resources-members/reports/plastics-market-watch.

introduced are made from raw materials such as food byproducts, wood, and sawdust. The next generation of bioplastics, many of which currently are in the laboratory stage, will come from algae and other organisms that are not associated with the production of food.

The terms "biobased" and "biodegradable" are sometimes misunderstood. These terms describe two unique attributes, but they are not mutually exclusive. A product can be both biobased and biodegradable. A product may also be biobased but not biodegradable. Similarly, a product may be biodegradable but not biobased. For example, a product may contain some polymers that are produced from fossil-based feedstocks that will break down over time; thus, this product is biodegradable but it is not a biobased product.

The confusion results from the fact that many people hear the word "bio" and assume the plastic was made from a plant, but this is not always correct depending on the source. As noted by Adam Gendell in an article in Packaging Digest,[50] a bioplastic can contain zero percent biobased materials and may be 100% fossil-based if it is, in turn, biodegradable (see Table 6). A bioplastic may be any combination of partially-biobased, fully-biobased, non-biobased, biodegradable, compostable, and non-biodegradable so along as it is NOT both non-biobased and non-biodegradable (lower left quadrant).

Table 6: Bioplastics as a function of source material and biodegradability status.

	Non-biodegradable	**Biodegradable**
Biobased	BIOPLASTIC	BIOPLASTIC
Fossil-based	PLASTIC	BIOPLASTIC

Other misperceptions about bioplastics exist, Mr. Krieger noted, including the idea that bioplastics are new, when, in fact, they have been around for many years. For example, the first natural plastics (rubber, horn, and tortoise shells) were bioplastics, and the first man-made plastic was also biobased and used cellulose from cotton. Mr. Krieger added that Henry Ford also worked to develop plastics using renewable resources. Another misperception about bioplastics, according Mr. Krieger, is that, polymers from a biobased feedstock will behave differently than the petroleum-based feedstock. In fact, biobased Polyethylene (PE) and Polyethylene Terephthalate (PET) are just as durable and recyclable as their petroleum-based counterparts.

Additionally, there is a misperception that biodegradable bioplastics will easily crumble. Mr. Krieger remarked that biodegradability relates to a very context-specific, which is why terms such as "industrial compostable" or "marine biodegradable" are used. Biodegradation rates depend on several factors, including the kind of bioplastic used in an application and the thickness of the product. For example, while logs and sticks in a forest are both "biodegradable," it will take the log a lot longer to decompose than the tiny stick. Also, the product's environment is an important determinant of the rate of degradation. "Industrial composting" is much more actively managed and attains a much higher temperature than "home composting." All bioplastics should be disposed properly to facilitate degradation, or they should be recycled appropriately. Not all bioplastics can be recycled. Bioplastics produced from

[50] Gendell, A., "It's Time for Bioplastics to be Plastics," Packaging Digest, March 11, 2017. http://www.packagingdigest.com/sustainable-packaging/its-time-for-bioplastics-to-be-plastics-2017-03-08.

polymer blends or that include biobased fillers may be difficult to recycle or may contaminate the existing recycling stream.

More than 21 bioplastic polymers are currently being used in the marketplace. The most commonly used bioplastic is biobased polyurethane (PUR) foams, which are commonly used in seat cushions, seat backs, and headrests in vehicles. PET is the second most commonly produced bioplastic, and it is frequently used for bottles, packaging, and some fabric applications. Bottling and packaging are the most common applications for bioplastics, but bioplastics are also being used in textiles, agriculture and horticulture, automobiles, building and construction, electronics, and consumer durables.

One of the driving forces for the use of bioplastics is that people are becoming more aware of the beginning-of-life benefits associated with sustainably-derived products and the end-of-life of products they use every day. At the beginning of life, bioplastics are made at least partly from sustainable resources (plants and other organic materials) rather than fossil fuels (natural gas, petroleum). At the end of life, the biodegradability and recyclability of bioplastics help reduce landfill usage and litter, and they also help avoid adverse effects on terrestrial and marine life. People are becoming more attuned to these benefits.

One of the biggest challenges in measuring the increasing use of bioplastics is the lack of a central repository for tracking sales revenue across product categories. Such data are important from policy and advocacy perspectives. It is difficult for organizations, such as PLASTICS, to make recommendations if they are unable to track progress and for the government to determine the effects of established policies. Mr. Krieger estimated that, currently, approximately one percent of polymers in the world are biobased. This estimate comes from a variety of sources, and there will always be variation among sources and depending on the definitions used. In some types of products, such as the biobased PET bottle, up to 30% of the global market is biobased, thanks in part to the sponsorship of organizations such as Coca-Cola.

The Future of Biobased Products

Mr. Krieger also noted that new biobased polymers beyond drop-in replacements for non-renewable polymers are being developed. Many of these innovative biobased polymers are being used because they have performance benefits that exceed those of current polymers. Examples include biobased Polyethersulfone and PET that are in development at DowDupont and BASF, which have higher density ratios and gap barrier properties. These characteristics might eventually lead to the replacement of petroleum-based PET, especially in the context of a robust recycling stream. These new biobased polymers (PES and PET) may lead to development of lighter weight bottles that can keep carbonated pressure longer. In addition, Mr. Krieger noted that there is research on renewable feedstocks that are from second and third generation sources.

Overall, the anticipated increase in the use of biobased polymers is very encouraging. The PlasticsEurope group recently reported increased production and increased investments in production capacity for biobased products and cited the increasing demand as being the most significant driver in their Annual Review[51]. The increasing demand for biobased products is also likely to drive down production costs because the scale that comes with higher volumes will drive down the unit costs of production as the processes become more efficient. Several companies, including Braskem, are expanding their production by using different polymers; for example, a new biobased monomer is being used in the production of PET. In fact, Braskem has developed a biobased polyethylene that will be used by Lego in a new line of toy products. These trends suggest that the owners of the larger consumer brands are becoming more comfortable in experimenting with the use of new bioplastics. There are three main reasons for their interest in new uses of bioplastics.[52]

- Consumer interest – Consumers are demanding more sustainable products, and a recent study showed that people are willing to pay a little more for biobased products.
- Company interest – Since companies increasingly are being asked to produce end of year sustainability reports, they are looking for new ways to reduce carbon emissions, reduce water usage, and increase sustainability. These companies are seeking ways to attain both cost savings and sustainability increases, and biobased products are a great opportunity to make an impact.
- Policy-based drivers – Section 9002 of the 2002, 2008, and 2014 Farm Bills mandates that federal acquisition officers buy biobased products is categories designated by USDA when possible. This is having an increasing impact over time.

To drive growth further, Mr. Krieger emphasized that education is key. For instance, Coca-Cola did a test to determine how long it took to explain to a consumer what a bioplastic package (PET) is, and the answer was three minutes! Despite that, the Company plans to be using sugar cane in all of its plastic bottles by 2020. They also are working with a new company, Virent, to develop a bottle comprised entirely of plant-based materials. However, the good news is that once consumers understood what biobased plastic meant, they immediately developed favorable opinions of biobased products and packaging. Mr. Krieger noted that, "The challenge is that, generally, people will not listen to an infomercial or commercial for three minutes, so other ways are needed to increase awareness. Also, some people may claim that they have never used bioplastics, even though they may drive a Ford with biobased seat cushions, drink a Coke from a biobased PET bottle, and use a biobased INGEO fork and plate at a professional sporting event."

Additional education also is needed to dispel many of the myths that surround bioplastics. For instance, one myth is that bioplastics use vital food resources and that agricultural feedstocks for bioplastics would be better used to provide food for populations around the world. But according to European Bioplastics, only 820,000 hectares were used to grow renewable feedstocks in 2017, which represents less than 0.02% of the global agricultural area of five billion hectares.[53] There is no doubt that the growth of bioplastics will continue and will offer customers new options based on societal trends and consumers' demands.

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[51] "PlasticsEurope Annual Review 2017-2018," PlasticsEurope Association of Plastics Manufacturers, accessed May 2018. https://www.plasticseurope.org/en/resources/publications/498-plasticseurope-annual-review-2017-2018.
[52] "PlasticsEurope Annual Review 2017-2018," PlasticsEurope Association of Plastics Manufacturers, accessed May 2018. https://www.plasticseurope.org/en/resources/publications/498-plasticseurope-annual-review-2017-2018.
[53] "PlasticsEurope Annual Review 2017-2018," PlasticsEurope Association of Plastics Manufacturers, accessed May 2018. https://www.plasticseurope.org/en/resources/publications/498-plasticseurope-annual-review-2017-2018.

2.5.3 Case Study: Procter & Gamble

Procter & Gamble (P&G) has a large consumer research and development group that is focused on continuously exploring new materials for its fabric care product category. Will Shearouse is the lead formulator, and he works in the lab and with emerging suppliers to test new products intended for the marketplace.

In an interview, Dr. Shearouse remarked that P&G is always focused on the consumer and exploring ways to delight consumers. In recent years, his team has seen increasing consumer interested in more sustainable and natural products.

Dr. Shearouse explained that this trend aligned well with the fabric care division's objectives; they could see that consumers were calling for more sustainable products, and P&G also was seeking to become more sustainable as an organization. Accordingly, Dr. Shearouse and his team set about seeking to create a laundry detergent that was sustainable, starting with the largest brand, Tide. Their objective was to create something that spoke to consumers' desire for sustainable products but that had the same cleaning properties as Tide. Thus, his team began to explore what renewable materials were available and could meet this objective.

Early in 2015, Dr. Shearouse put together an R&D team to explore materials. The team started with original Tide and began exploring the materials. Dr. Shearouse noted that P&G produces more surfactant than any other company in the world, and the Company does a lot of research and development on natural surfactants in its labs. Dr. Shearouse explained that the R&D team wanted to find a biobased surfactant that could clean in cold water because warming the water itself is the number one source of energy consumption in the washing cycle. Moreover, the team used a holistic life cycle analysis to explore the entire washing cycle that included both the required temperature of the water and the nature of the product material.

Dr. Shearouse reported that the team worked with external partners on the development of enzymes that worked with lower temperatures, and they also considered the use of other renewable materials, such as fatty acids, that would soften the water during the washing cycle. The team focused on renewable materials, keeping in mind that cleaning performance was the most important aspect. Dr. Shearouse emphasized that if a consumer experiments with using a product that competes with original Tide and finds that it does not work as well, the consumer will immediately switch back to original Tide. Consequently, environmentally preferable chemicals will have difficulty becoming mainstream until they are as effective as or more effective than traditional chemicals.

Tide purclean™ is:

- The first plant-based detergent (65% plant-based) with the cleaning power of Tide
- A USDA Certified Biobased liquid laundry detergent
- Manufactured using 100% renewable wind power electricity[54]
- Made with no manufacturing waste sent to a landfill

[54] The same facility also uses steam power; electricity represents approximately 50% of total energy used.

- Designed free of dyes, chlorine, phosphates, and optical brighteners (The unscented variant also is free of perfumes.)
- Available in Honey Lavender scent and unscented variants

Dr. Shearouse asserted that the most significant development challenge for renewable, biobased materials is to solve the balance of meeting performance objectives and affordability. He also noted that, for original Tide, the majority of materials are all synthetically derived, and this is fine so long as the price of petroleum stays low, which allows for the efficient production of these materials. Dr. Shearouse added that, in his team's research, they found that the cost of biobased materials was 10-15% lower than the original Tide. He also emphasized that if consumers are driving companies to explore more renewable materials, companies will have to respond in a creative manner to develop alternatives that are affordable.

Dr. Shearouse shared that Tide purclean™ currently contains 72% biobased content. However, P&G chose to display a label that lists the content at only 65% due to potential variability in the feedstock supply and the fact that the Company wanted to ensure that the product was always in compliance with the label. Concerning the USDA Certified Biobased Product label, to date, P&G cannot specify what the impact on sales has been, and the team realizes that customers still have a lot of skepticism about products that claim to be more sustainable. However, Dr. Shearouse noted that the USDA BioPreferred Program's label provides a solid third-party credential to show consumers P&G's products are not being "greenwashed" (claiming to be sustainable without a solid basis for the claim). Dr. Shearouse went on to say that P&G wanted to help the consumer feel confident that their products' sustainability claims are real, and the USDA Certified Biobased Product label brings that level of authenticity to the brand, although P&G's research suggests that many consumers are not yet aware of the BioPreferred Program.

The other important differentiator of the BioPreferred Program's certification, according to Dr. Shearouse, was with the trade retailers. The certification had a very positive impact with the buyers and category managers at these retailers. Additionally, the third-party certification proved to these trade consumers that P&G had taken a significant step forward, and that has been incredibly valuable to their brand

The BioPreferred Program's USDA Certified Biobased Product label recognizes innovation for companies that are exploring the development of renewable materials, and Dr. Shearouse stated that this will have a significant role in shaping the future of Tide and other products produced by P&G. Also, Dr. Shearouse explained that the BioPreferred Program's label provides motivation for the development of new polymers as the Company explores using these materials in their new products. The BioPreferred Program's certification process is transparent and there is a clear, analytical method to ascertain the percentage of biobased material. This aligns very well with the way that P&G and other companies view innovation.

In addition, Dr. Shearouse stated that financial incentives will drive sustainability increases. He went on to note that any type of government program that drives down the cost of renewable materials or rewards companies if they use these materials also will help drive down cost and improve performance. Dr. Shearouse believes that scientists must always focus on managing performance, but it is also important that they manage the affordability of the product. Tide purclean™ is a great success story because it shows how both challenges were addressed. Dr. Shearouse shared that, since the success of Tide purclean™, P&G is aware that there are opportunities to expand its sustainable product offerings in other areas, including fabric care, fabric enhancers, and beauty products, and the Company will continue to pursue these opportunities.

2.6 Enzymes

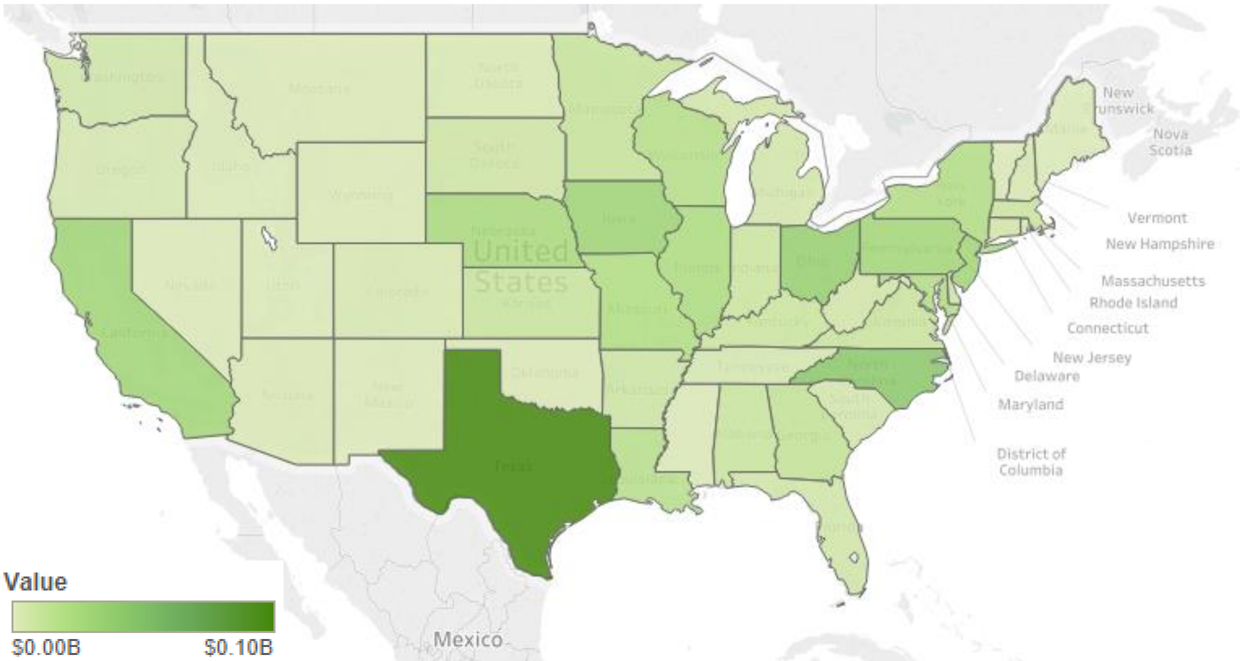

Figure 18: Total Value Added Contributed by the Enzymes Industry in Each State and the District of Columbia in 2013.

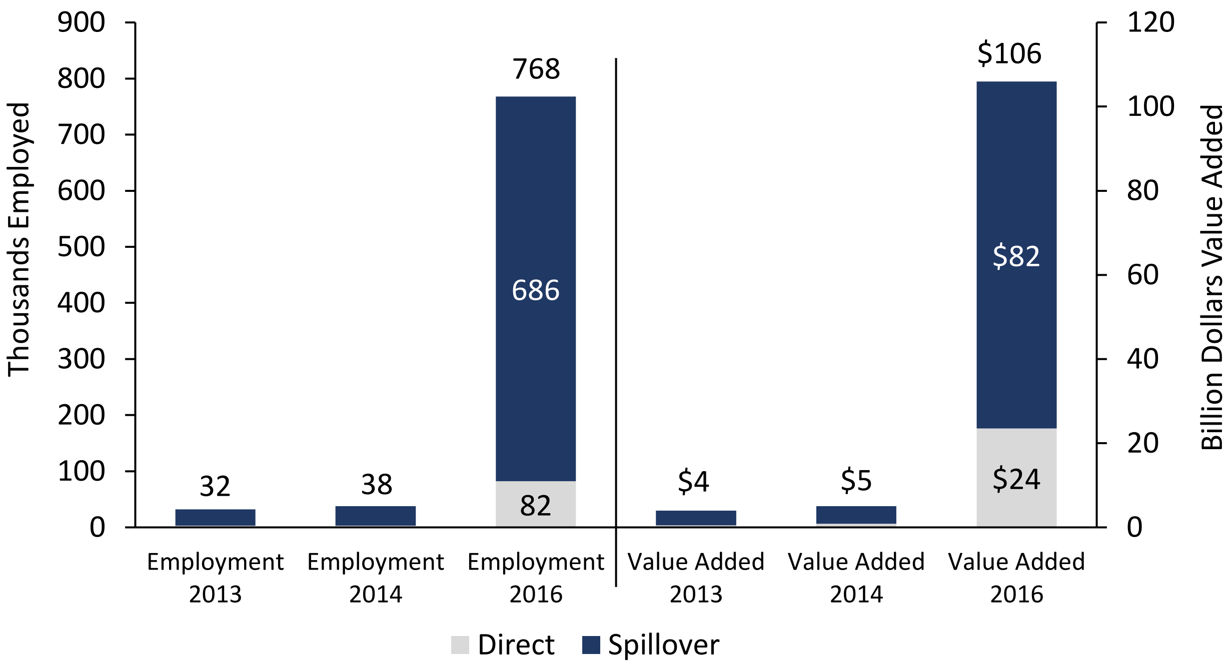

Figure 19: Enzymes Contribution to Employment and Value Added in 2013, 2014, and 2016.

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% in the period 2017-2022.[55]

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 2016: $106 billion
Exports value added to the U.S. Economy in 2016: $31 billion
Type SAM Economic Multiplier in 2016: 4.51

Employment Statistics
Total number of Americans employed due to industry activities in 2016: 768,000
Total number of Americans employed due to industry activities supporting exports in 2016: 222,000
Type SAM Employment Multiplier in 2013: 9.34

Table 7: Distribution of Direct Value Added and Employment by Enzymes Sub-Sectors.

IMPLAN Code	NAICS Code	Description	Employment	Value Added
165	32519	Other basic organic chemical manufacturing	52,170	$11,468,000,000
176	325414	Biological product (except diagnostic) manufacturing	30,090	$12,035,000,000
		Totals	82,260	$23,503,000,000

2.6.1 Enzymes Industry Report

2.6.1.1 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; they also are used in several other industrial sectors, such as paper and pulp, wine making, 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

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

grow at a CAGR of 5.6% in the period 2017-2022.[56] This positive outlook is owed to a number of factors, ranging from government legislation to growing demand in a number of key industries.[57] 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.[58] New research in forensics and molecular biology will also help drive innovation and meet demand.[59] Figure 20 shows the applications of the North American specialty enzymes market.

Enzymes are produced and found in the cells of all living organisms. Enzymes are proteins that produce specific chemical reactions and are the foundation for the metabolism of living organisms. These reactions speed up biochemical processes, making them more efficient by using less energy and resources. Humans have been using enzymes to produce biochemical reactions for thousands of years, with the earliest example being the fermenting of crops into wine and beer. While there are more than 4,000 recognized enzymes in the world, it is estimated that more than 25,000 exist in the natural world. With an estimated 90% of enzymes yet to be classified, this 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. .

[56] Mordor Intelligence report: United States Industrial Enzymes Market, 2016, accessed March 2018. https://www.mordorintelligence.com/industry-reports/united-states-industrial-enzymes-market.
[57] Grand View Research: Enzymes Market by Type, Market Research Report, accessed March 2018. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.
[58] Grand View Research: Enzymes Market by Type, Market Research Report, accessed March 2018. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.
[59] Grand View Research: Enzymes Market by Type, Market Research Report, accessed March 2018. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.

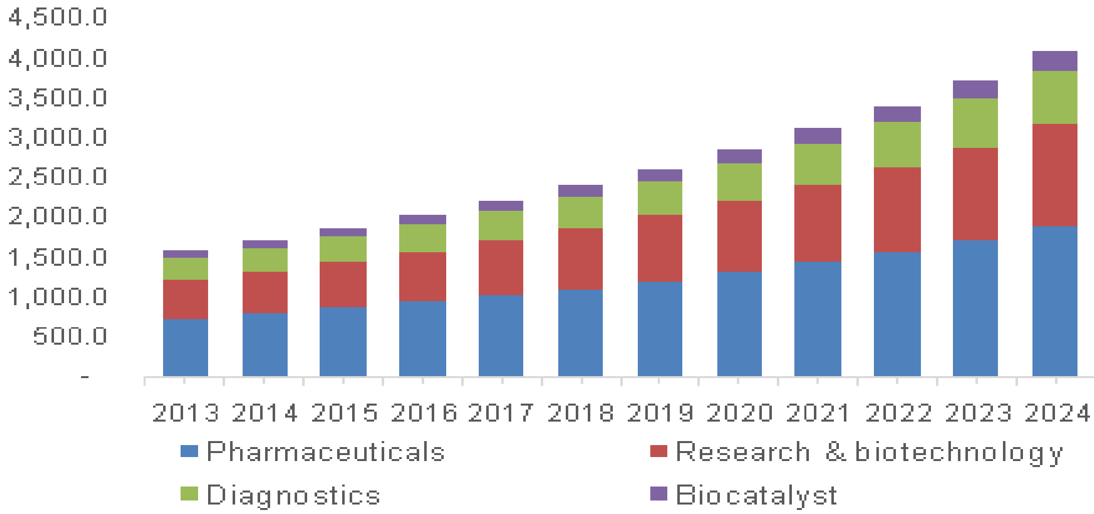

Figure 20: North American Specialty Enzymes Market, by application, 2013-2024 (USD Millions).[60]

[60] Grand View Research: Enzymes Market by Type, Market Research Report, accessed March 2018. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.

2.7 Biobased Plastic Bottles and Packaging

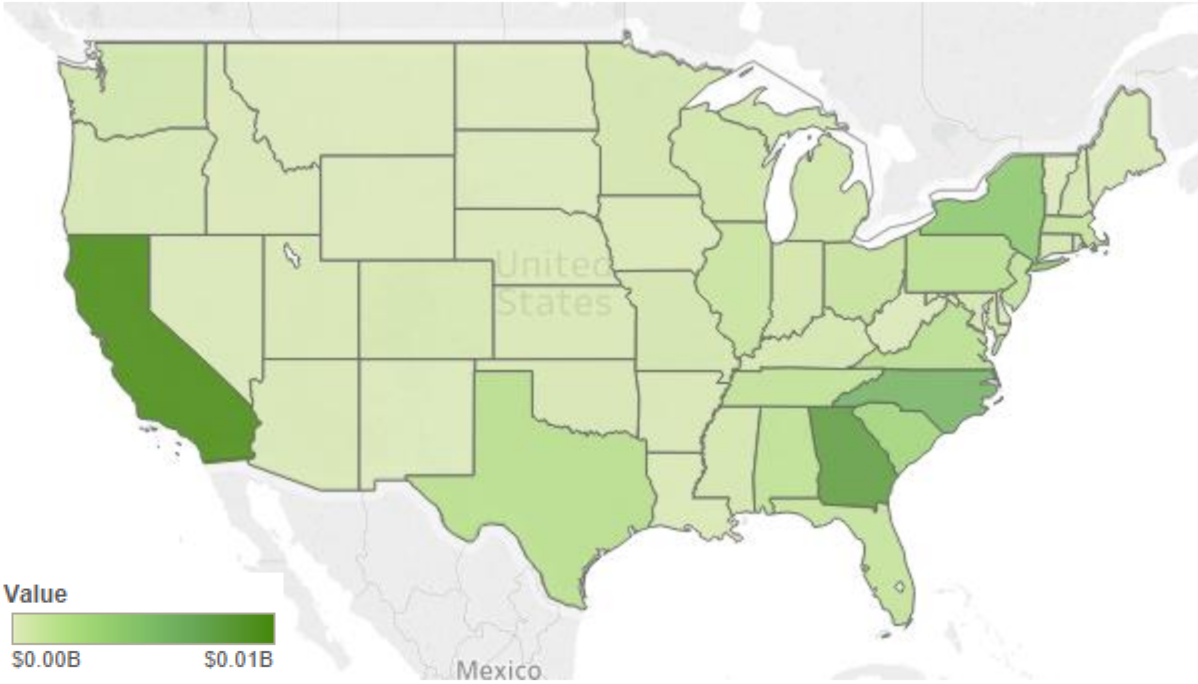

Figure 21: Total Value Added Contributed by the Biobased Plastic Bottles and Packaging Industry in Each State and the District of Columbia in 2013.

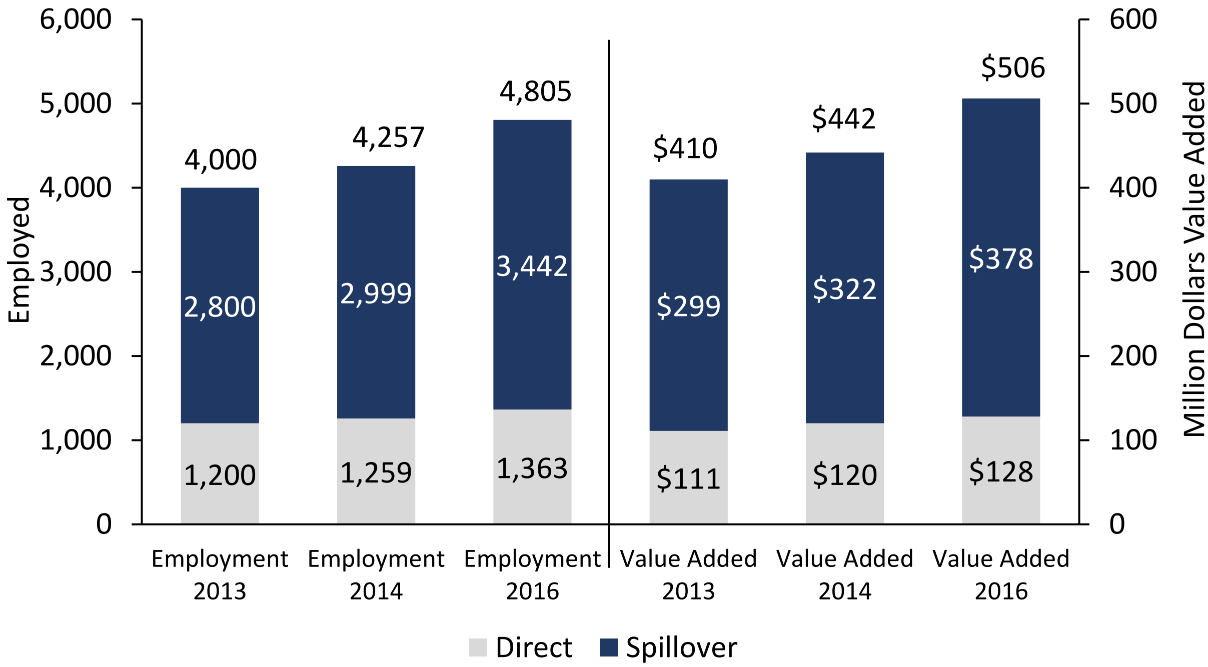

Figure 22: Biobased Plastic Bottles and Packaging Contribution to Employment and Value Added in 2013, 2014, and 2016.

The biobased plastics manufacturing industry is relatively young and has a positive growth forecast estimated at 4.5% over the next five years to 2023. Drop-in solutions represent the single largest sector of the 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.[61]

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 2016: $506 million
Exports value added to the U.S. Economy in 2016: $58 million
Type SAM Economic Multiplier in 2013: 3.95

Employment Statistics
Total number of Americans employed due to industry activities in 2016: 4,800
Total number of Americans employed due to industry activities supporting exports in 2016: 560
Type SAM Employment Multiplier in 2016: 3.53

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

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
195	32619	Other plastics product manufacturing	910	$71,000,000
188	32611	Plastics packaging materials and unlamented film and sheet manufacturing	280	$35,000,000
194	326160	Plastics bottle manufacturing	90	$12,000,000
189	326121	Unlamented plastics profile shape manufacturing	80	$10,000,000
		Totals	1,360	$128,000,000

[61] 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.

2.7.1 Biobased Plastics Industry Report

2.7.1.1 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% over the next five years 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% 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.

2.7.1.2 Exports

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

2.7.1.3 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, i.e., cellulose-based, glucose-based, starch-based, and synthetic-based biobased plastics.

Cellulose-based biobased plastics represent about 15% of the sector's revenue. Cellulose materials, such as acetate, are modified from sources such as cotton, hemp, and wood pulp. Then, these plastics are used in a wide range of applications, from packing confectionaries to CDs. 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 they are used to make food packaging, including cups, bottles, carpets, and clothing. These plastics account for 10% of the sector's revenue.

The sale of starch-based biobased plastics contributes an estimated 55% 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, including lignin-based biobased plastics, which use byproducts from the paper-milling industry. Synthetic- based plastics make up about 20% of the industry's revenue.

2.7.1.4 Markets

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

Packaging comprises the largest share of the market for biobased plastics, accounting for 36.5% 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% of the industry, with industry leaders, such as Coca-Cola, providing the largest markets. Increasing awareness of global environmental issues and the desire to appeal to consumers' concerns are the main drivers of growth. Concern about petroleum-based plastics emitting toxins into drinking water and about increasing prices for oil also benefits this sector. Volatile 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% of total revenue.

2.7.1.5 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% 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: Biobased plastics in the Food Service Industry*

While preparing this report, we interviewed several leading experts in the food service packaging industry, which is using increasing amounts of biobased plastics, especially PLA, for serving food. Each of these interviews provided a different set of insights that, considered together, portrayed a growing sector. We interviewed experts at the Foodservice Packaging Institute (FPI), NatureWorks, Biotechnology Innovation Organization (BIO), Eco-Products, and Asean Corporation. NatureWorks is the manufacturer of the Ingeo material.

Lynn Dyer, President of the FPI, has spent her career working at the FPI, and she has emerged as one of the true experts in this area. The FPI was formed in 1933 and is an advocate for the industries that produce the food containers, bags, cutlery, and straws that are used in restaurants and cafeterias. The FPI is material neutral, and represents companies producing products with biobased materials as well as petroleum-based materials.

Ms. Dyer noted that throughout her 20-year career in the food service packaging industry she has always hesitated to say that renewable materials are a trend. She went on to say that, currently, renewable materials are really just part of the business. Ms. Dyer also remarked that she dislikes the terms “green” and “environmentally friendly”, preferring instead terms that are well-defined such as “renewable,” “compostable,” “produced from recycled content,” or “biobased.” Additionally, Ms. Dyer said that she is beginning to see more interest than ever in renewables, biobased products, beginning of life attributes, and renewable/compostable food service products.

Performance and cost are the most important product attributes. For example, it is difficult to find a replacement for foam polystyrene to use for frozen beverages like a milkshake. Styrofoam has been used for years, and trying to find an alternative that insulates as well as foam is important, to avoid the milkshake melting quickly. However, there are several emerging products, such as molded fiber, that might be able to replace foam. Molded fiber is also known as molded pulp, and usually made from recycled newspaper and water. This replacement would have to work well to move people away from plastics, and the cost also will be a factor. Pricing performance is very important in food packaging, and a price point above the minimum is difficult to justify. In this case, a molded fiber milkshake cup could compete with foam, and such fibers also could be used in plates and bowls. However, there also are emerging technologies that use a biobased resin.

Ms. Dyer also believes that the USDA BioPreferred Program’s certification label must become generally recognized if it is to become really effective, especially in the food service packaging industry. However, large companies, such as McDonalds and Starbucks, may not want to put an additional symbol on their cups that competes with their brand image. Thus, increasing consumer awareness of the USDA BioPreferred Program’s label may be difficult to accomplish, even though some large companies may sell products using packaging that is part of the BioPreferred Program. Thus, it may be better for the BioPreferred Program to work with large companies and also work with the Biodegradable Products Institute (BPI) to advance their mutual goals.

According to Ms. Dyer, when PLA coating on paper cups first was introduced 15 years ago, there were serious performance and pricing issues with the cups. In particular, there were complaints about the performance when paired with hot liquids. Today, however, PLA coating on cups can compete based on performance, and the cost is only slightly higher. One of the real benefits of PLA and NatureWorks' Ingeo foodservice-ware is that it is compostable. Cups and take-out containers decompose faster than a piece of cutlery because they are thinner. The material and the thickness are important, and a thick, molded-fiber egg carton will take a long time to decompose. The BPI certifies whether products are compostable using specifications and tests that were developed in 2002 that demonstrate that a material will biodegrade and leave no persistent synthetic residues. The standard ASTM D6400, applies to compostable plastic products, and the standard ASTM D6868, applies to products that use compostable plastic coatings. Products certified based on these standards can use the BPI label.

The FPI notes that, currently, foodservice packaging is approximately half paper, which is inherently biobased, and half plastic in terms of units. Considering plastic foodservice packaging, the biobased product sector is still nascent, and biobased products currently account for a very low percentage of the volume, whereas plastic containers that use petroleum-based polypropylene, PET, and polystyrene account for much larger percentages. As more and more companies adopt the sustainability goals their customers are asking for, they are beginning to consider sustainable packaging much more seriously, and decisions are being made by these companies to move towards biobased products. Additionally, an "anti-plastic" sentiment is emerging and being promoted by groups such as NGO's, where are indicating their preference for less reliance on plastic.

Evidence of this trend is already evident in Europe. The European Union is considering a proposed total ban on some single-use plastic products that would also prohibit giving away plastic food containers and drink cups free of charge.[62] In addition, a new international study by Unilever indicated that 33% of consumers favor products from companies they believe are socially or environmentally beneficial, which represents an estimated one trillion dollar opportunity.[63]

One of the big changes occurring in the food service packaging industry is the use of biobased food containers at sports events. Stadiums are "closed loop" systems, meaning that all of the waste materials can be collected and sent to a composting site where it can be more efficiently put through a biodegradable process. One benefit of this is that it allows the facility to control the flow of waste, cutting down on the amount of contamination, such as a mixture of non-biodegradable and biodegradable material, in a waste stream. As the amount of contamination increases in the composting stream, it is increasingly difficult to separate the materials, and this increases the cost of composting. In the case of restaurants, though customers can be asked to put their biodegradable materials in one bin and plastic in another bin, they may or may not comply.

[62] Pronina, L., "EU Proposes a Total Ban on Plastic Forks and Other Products," Bloomberg website, May, 28, 2018. https://www.bloomberg.com/amp/news/articles/2018-05-28/life-in-plastic-not-fantastic-eu-says-in-clampdown-proposals.
[63] "Report shows a third of consumers prefer sustainable brands," Unilever website, May 1, 2017. https://www.unilever.com/news/Press-releases/2017/report-shows-a-third-of-consumers-prefer-sustainable-brands.html.

We spoke with several providers of food service containers who confirmed and elaborated on the growth of biodegradable waste streams.

Eco-Products, Inc. – Growing across All Segments
Eco-Products is one of the largest and most recognized brand of biobased, environmentally-sound food service packaging products. As category leaders with an exclusive commitment to environmentally-preferred packaging, the company produces more than 350 Stock Keeping Units (SKUs) that are certified by the USDA’s BioPreferred Program and BPI.

The term “Zero Waste” is in Eco-Products’s vision and mission, and, as Sarah Martinez of Eco-Products indicated, the Company believes that single-use packaging can be part of a circular economy by rethinking where packaging comes from, its role in consumer use, and how it is disposed of. Eco-Products sells primarily through distributors, such as US Foods and Sysco, but it also sells through college, sports, and concert venues; restaurants; healthcare facilities; and others. Eco-Products’ focus is on food that is prepared, served, and eaten almost immediately. The Company has continued to grow through the years, thanks in part to the increase in the composting of food service packaging products. The growth of companies such as Eco-Products will continue as long as the collection and processing of food packing products expands.

Most of the manufacturing of Eco-Products’ products is done in Asia, in part using materials produced by NatureWorks. Large customers, such as US Foods are always asking about certification, and the USDA Certified Biobased Product label is seen as an important criterion to ensure that Eco-Products’ products are biobased. In addition, the BPI verification of compostability is another key part of the brand’s attributes.

There are several challenges associated with compostable foodservice packaging. First, a composter that is equipped to handle the waste stream must be available. Another challenge is the contamination that occurs when the composter receives non-compostable foodservice packaging along with food waste. At major sporting events, people may not read the disposal bin signs, and throw all of their waste materials into the same bin. This creates a problem because composters want food waste and recyclers do not want food waste. This problem could be solved by working with end users and convincing them that they should only buy compostable foodservice packaging. When a foodservice operator commits to buying only compostable packaging, the composters can accept and process both the packaging and the food.

Eco-Products has agreements with multiple sporting venues, including the Seattle Mariners, the Minnesota Twins, and the Minnesota Vikings, and the Company provided the foodservice packaging for the first-ever, zero waste Super Bowl in January 2018 in Minneapolis. The Green Sports Alliance promotes many of these efforts.

There are several entities that can provide additional insights into the area of compostable biobased packaging. The Compost Manufacturing Alliance is conducting field disintegration testing for manufactured products. The Alliance offers a program of technical review and field testing of compostable products to determine their feasibility as a feed stock when shipped to fully-permitted industrial composting facilities. Additionally, the New Plastics Economy Initiative applies the principles of the circular economy and determining how to avoid polluting the oceans with the increasing output of non-renewable plastic material.[64]

Asean Corporation's StalkMarket, the Portland Trail Blazers, and the Moda Center

StalkMarket®, an Asean Corporation brand, is a leading supplier of 100% compostable, plant-based coffee cups, lids, tableware, cutlery, and food packaging. All of the Company's products are certified by BPI to be compostable, and they are made from all-natural and sustainable resources. Asean's StalkMarket brand of Ingeo-based foodservice ware has been growing steadily in the last few years, and the StalkMarket logo is easy to find on a walk through any of Portland's many coffee shops and restaurants. An interview with Buzz Chandler, President of Asean Corporation, showed how this biobased product brand came to be accepted in the local community.

Mr. Chandler remarked that the Company fell into the biobased product industry in 2003 by accident. He noted that the Company was involved in exporting frozen seafood to Asia at the time, and their partner in Hong Kong mentioned that they might be interested in sugar cane products such as burger boxes and plates. As a result, the Company began contacting vendors to gage their interest in biobased products. Mr. Chandler reported that one of the retailers they had contacted was a natural food chain in Portland, and they responded very positively to the idea. That chain of events in 2003 led to millions of dollars in sales and growth of the Company's brand.

[64] "How might we get products to people without generating plastic waste?" OpenIDEO website, accessed July 2018. https://challenges.openideo.com/challenge/circular-design/brief .

Not long after StalkMarket began marketing their products made with Ingeo, Mr. Chandler met with the front office team at the Moda Center. Mr. Chandler recalled that the team was drinking coffee from StalkMarket's Plant+ cup. Two weeks after the meeting, StalkMarket was a full sponsor partner for all solid waste and compostable products in the Moda Center. Mr. Chandler noted that StalkMarket is a long-term partner, and it is diverting over 5,000 pounds of waste per month from landfills, which includes the diversion of a lot of packaging. Figure 23 shows the results of the Portland Trail Blazers' waste diversion program from 2008 to 2013.

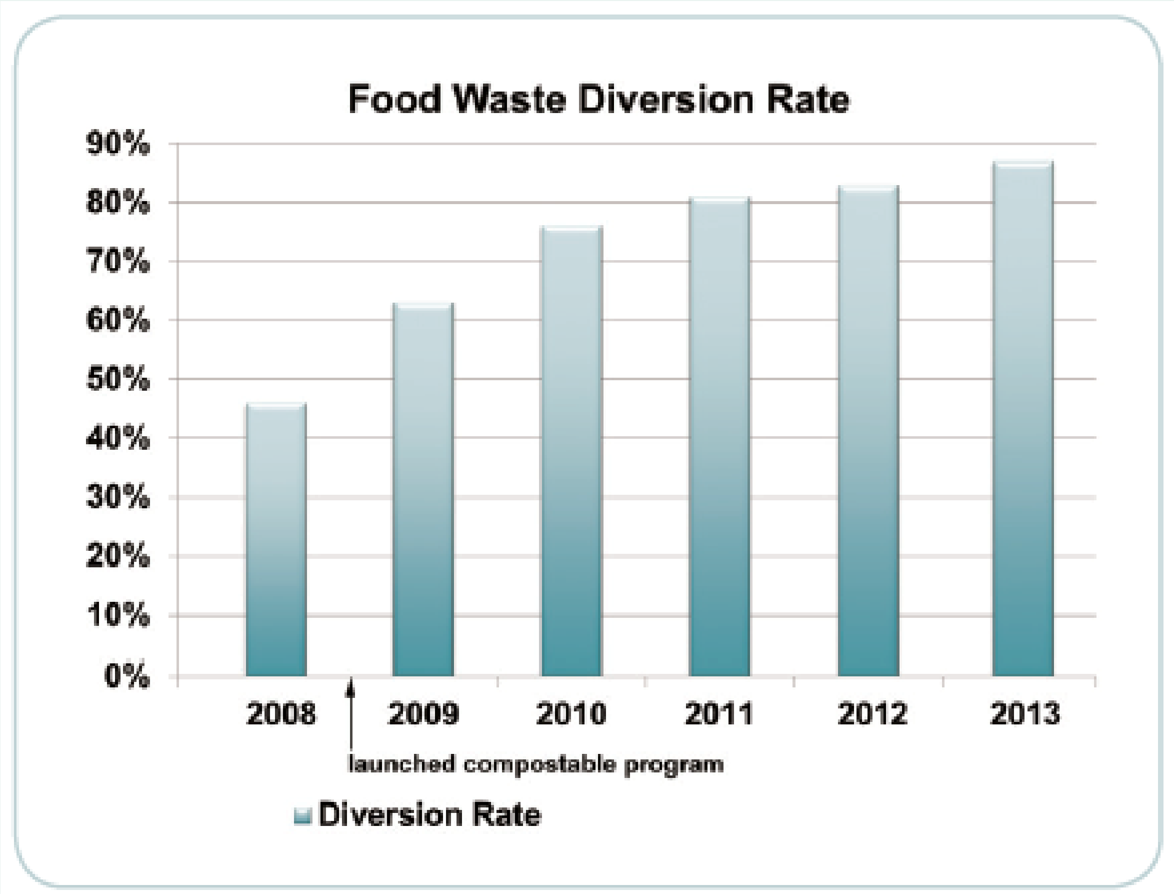

Figure 23: Food Waste Diversion Rate and Launch of the Compostable Program.[65]

[65] "Portland Trailblazers & the MODA Center Introduce Compostable Serviceware," NatureWorks website, accessed July 2018. https://www.natureworksllc.com/Ingeo-in-Use/CaseStudies/Portland-Trail-Blazers-Moda-Center-Use-Ingeo-Food-Serviceware.

According to NatureWorks,

Just a few of the key stakeholders included:

- *Portland Trail Blazers - set out to reinforce their brand; set the goal of diverting 100% of the waste from the landfill; sought to win additional public support*
- *Ovations Food Service - made procurement switch to compostable products and achieved price parity; engaged staff effectively*
- *The Moda Center - operations sought to enhance the experiences of fans and guests; enabled infrastructure and capital investments to make the initiative possible, including critical recycling stations as guest engagement and waste stream separation mechanisms*
- *StalkMarket Products - supplied BPI-certified, compostable, Ingeo-based drink cups and food service packaging to Ovations' concessions centers*[66]

In addition, the Trail Blazers are working with a company that hauls waste to a composting site. To close the loop, the stadium's landscaping company buys the composted food waste and uses it to fertilize the plants and lawn on the site.

Through this effort, the Trail Blazers were able to show that being conscious of their environmental footprint has positive results on the bottom line. It has saved the Trail Blazers over a million dollars through reduced haulage and reduced landfill costs, which has directly affected their bottom line.

Several important elements led to the success of this effort. First, the design of the waste receptacles in the Moda Center was important to ensure that compostable waste was collected properly. The new "GreenDrop" recycling stations and sorting signage ensured that food and packaging waste streams could be combined into a single compostable waste stream to avoid ending up in a landfill. These stations were custom designed through the efforts of the Portland Trail Blazers' Head Office to reduce their environmental footprint while minimizing expenses and being fiscally responsible through sustainable operations. The partnerships between concessions and StalkMarket's Ingeo-based BPI-certified foodservice ware and other compostable offerings were vitally important to the success of the project.

[66] "Portland Trailblazers & the MODA Center Introduce Compostable Serviceware," NatureWorks website, accessed July 2018. https://www.natureworksllc.com/Ingeo-in-Use/CaseStudies/Portland-Trail-Blazers-Moda-Center-Use-Ingeo-Food-Serviceware.

Many other sports and entertainment venues are starting to take notice. In fact, the Green Sports Alliance is bringing on more teams from the National Hockey League, Major League Baseball, the National Basketball Association, and Major League Soccer. Other teams, including the Minnesota Twins, the Pittsburgh Pirates, and the Minnesota Wild, and universities, including Purdue University and Pennsylvania State University, are also interested. As previously mentioned, the 2018 Super Bowl in Minneapolis utilized this same composting waste stream approach, using Eco-Products' serviceware. Sports fans across the country may find themselves drinking from compostable cups and using compostable cutlery at the next sporting event they attend.

2.7.3 Case Study: SelfEco

SelfEco is a third generation manufacturer of biobased plastic cutlery and flower pots, which its President, Danny Mishek, sought to transition from a traditional manufacturer to one that seeks to capitalize on past technology to produce products that are environmentally preferable and sustainable. The Company was started in March 2015 when the U.S.-based custom manufacturer VistaTek introduced SelfEco, a new, independent Company manufacturing plant-based plastics in the U.S. Mr. Mishek noted that the Company's goal is to "create things differently than previous generations" by mindfully manufacturing products that can be composted, recycled, or reused. The Company began by producing compostable and affordable caterware, cutlery, and drinkware designed for the catering and food service industry. The use of compostable cutlery is increasing in many areas, especially in large public forums, such as the Minnesota Twins' stadium. The managers of these venues want to get away from sorting and separating glass, plastic, and compostable items, thereby making operations easier and reducing the associated costs.

SelfEco's products are formulated with sustainable materials, primarily PLA, and manufactured using traditional technology. The Company has expanded its product focus from recyclable cutlery into plastic garden pots. While biobased PLA cutlery is produced by several companies, the biobased planting pot business is a newer idea with less competition.

Planting Pots

The variety and number of plants grown in pots is astonishing. In the United States alone, more than 4.5 billion containerized plants per year are produced by the horticulture specialty-crops industry and nearly all of them are grown in single-use, petroleum-based plastic pots. Efforts are made by producers to re-use or recycle some of these pots, but the unfortunate reality is that the success rate is less than 2%, and a staggering 98% of plastic pots end up in the solid waste stream. Thus, pots used in horticulture that are made of biobased plastics and biocomposites have a high potential as a sustainable alternative to petroleum-based plastic pots. A book was recently published by Iowa State University's Sustainable Horticulture Research Consortium that provided the first comprehensive report on the development and utilization of biobased plastic pots for use in the field of horticulture. The book covers various topics, such as the development, availability, cost, processing, performance, biodegradation, economic feasibility, marketability, and sustainability of biobased plastic pots. In addition, it illustrates how the pots provide all of the functional advantages of petroleum-based plastic pots, while strongly increasing sustainability and reducing environmental impacts.

Mr. Mishek worked in manufacturing for 18 years before becoming the President of SelfEco. The Company's initial cutlery products, which were made entirely from plant-based plastics and compostable, and they are becoming increasingly popular as companies ban traditional plastics. However, it is the compostable pots that are generating a great deal of excitement in the industry.

Petroleum-based plastic pots have been the industry standard for horticultural pots for almost 75 years. Although they are extremely effective, their continued widespread use is not sustainable. Biobased plastics and biocomposites have demonstrated strong potential as high-performing, sustainable alternatives in a number of applications, and their specific characteristics make them especially promising for use in horticultural pots. Biocomposites are composed of biobased plastic resin blended with natural fibers or fillers.

Although traditional plastic pots are functionally excellent for plants, they can have some major disadvantages, such as root circling of some medium- and long-cycle crops. Another disadvantage is dark-colored pots can absorb too much radiation from the sun, causing high root-zone temperatures.[67]

SelfEco has developed a compostable garden pot made out of PLA. The compostable design naturally breaks down over time and helps feed the plants. This new formulation permits the gardener to plant the entire pot in the ground and allows the roots to come out of the pot and become better established. The plant pots contain all-natural distiller's dried grain with solubles (DDGS) that is incorporated directly in the walls of the pots, allowing it to act as a protein-rich plant food that feeds the plants. DDGS is a by-product in the production of whiskey and ethanol. In other applications, it is fed to pigs or disposed as waste. Because it is rich in protein, it has proven to be an effective plant food. Customers especially appreciate that they do not have to spend additional money to buy fertilizer. Adding fertilizer to the topsoil is not as effective as feeding the roots directly because the fertilizer may be diminished by rain and wind.

Currently, despite overwhelmingly positive feedback from customers, SelfEco has only a very small share of the plant pot and cutlery markets. Business obtained through retail and internet outlets are allowing SelfEco to grow slowly. The Company sells its products on Walmart.com, but some other large retailers are not convinced that the plant pot will benefit them, and they also are concerned that the product might decrease fertilizer sales. These companies have taken this stance despite the fact that objective studies have found that the amount of vegetables produced in a SelfEco pot is double or triple the amount produced using plastic pots. One reason for the retailers' resistance to selling SelfEco pots is that they are slightly more expensive than plastic pots, by approximately 5 to 7 cents per pot. In the supply chain, produce growers must be convinced that SelfEco pots provide greater yields that can offset the slightly higher initial cost.

[67] Schrader, J.A. "Bioplastics for horticulture: An introduction." In: Bioplastic Container Cropping Systems: Green Technology for the Green Industry edited by J.A. Schrader, H.A. Kratsch, and W.R. Graves. Ames, IA, USA: Sustainable Hort. Res. Consortium, 2016.

2.8 Forest Products

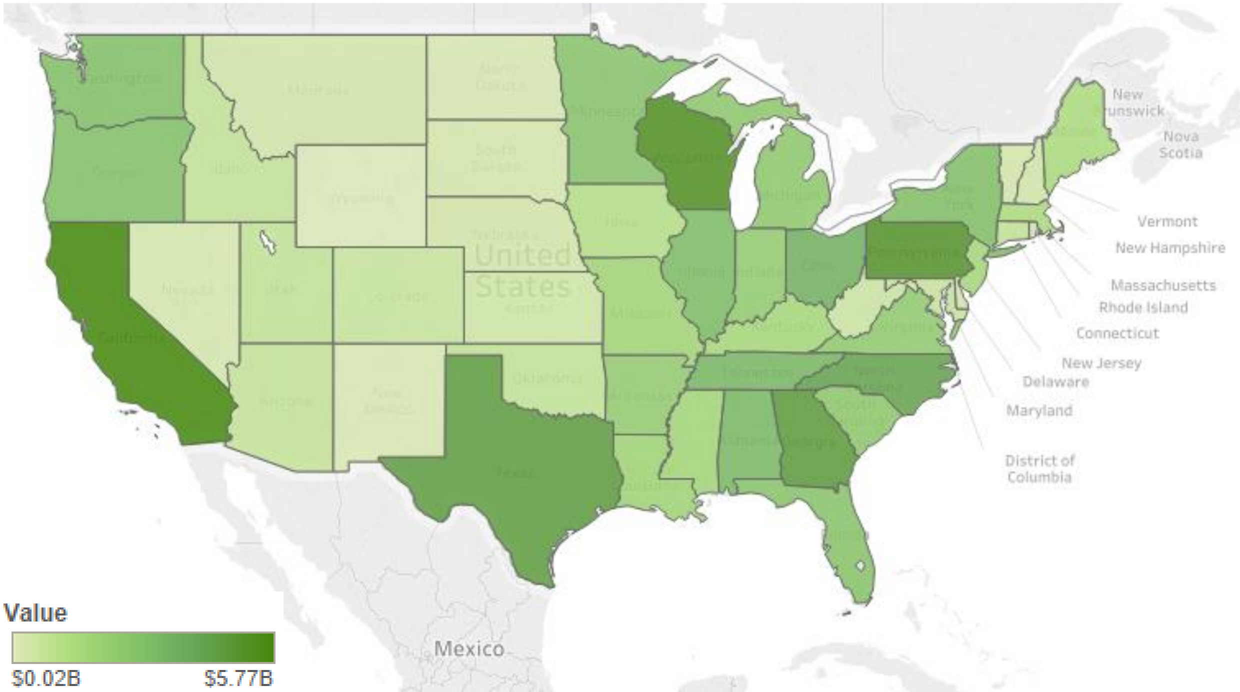

Figure 24: Total Value Added Contributed by the Forest Products Industry in Each State and the District of Columbia in 2013.

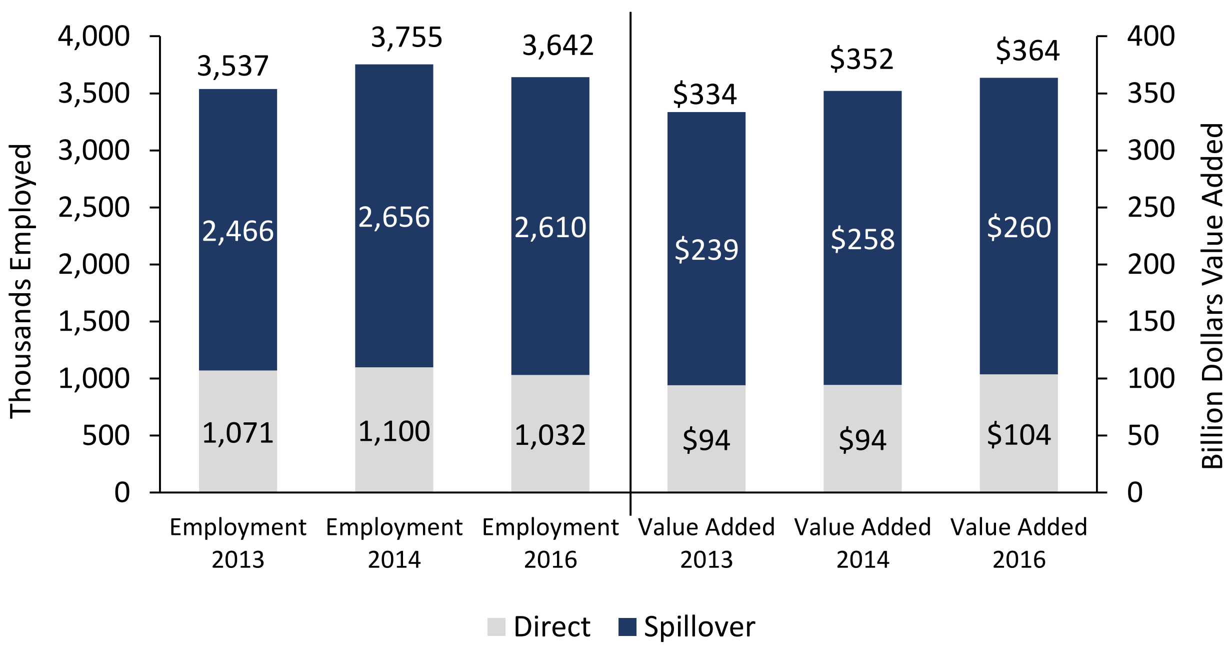

Figure 25: Forest Products Contribution to Employment and Value Added in 2013, 2014, and 2016.

A third of the United States, i.e., 760 million acres, is forested. Privately-owned forests supply 91% of the wood harvested in the U.S., state and tribal forests supply approximately 6%, and federal forests supply only 2%.[68]

Major U.S.-Based Firms[69]
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 2016: $364 billion
Exports value added to the U.S. Economy in 2016: 33 billion
Type SAM Economic Multiplier in 2016: 3.51

Employment Statistics
Total number of Americans employed due to industry activities in 2016: 3.6 million
Total number of Americans employed due to industry activities supporting exports in 2016: 313,000
Type SAM Employment Multiplier in 2013: 3.53

Table 9: 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	140,740	$15,254,000,000
368	337110	Wood kitchen cabinet and countertop manufacturing	114,950	$6,082,000,000
134	321113	Sawmills	95,100	$6,358,000,000
147	32212	Paper mills	66,260	$14,951,000,000
142	321920	Wood container and pallet manufacturing	56,140	$3,213,000,000
150	32222	Paper bag and coated and treated paper manufacturing	60,030	$7,912,000,000
369	337121	Upholstered household furniture manufacturing	51,740	$2,914,000,000
139	321911	Wood windows and door manufacturing	44,980	$3,555,000,000
141	321918	Other millwork, including flooring	36,190	$2,725,000,000

[68] American Forest and Paper Association (AF&PA), Fun Facts, AF&PA website, accessed April 2015. http://www.afandpa.org/our-industry/fun-facts.
[69] Forbes, The World's Biggest Public Companies, Forbes website, accessed April 2015. http://www.forbes.com/global2000/list/.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
370	337122	Non-upholstered wood household furniture manufacturing	41,670	$2,203,000,000
136	321211, 321212	Veneer and plywood manufacturing	29,700	$2,323,000,000
137	321213, 321214	Engineered wood member and truss manufacturing	30,150	$1,686,000,000
152	322291	Sanitary paper product manufacturing	28,980	$8,489,000,000
148	322130	Paperboard mills	30,850	$7,358,000,000
145	321999	All other miscellaneous wood product manufacturing	29,200	$1,888,000,000
372	337127	Institutional furniture manufacturing	21,510	$1,473,000,000
143	321991	Manufactured home (mobile home) manufacturing	20,190	$1,487,000,000
151	32223	Stationery product manufacturing	18,510	$2,174,000,000
374	337212	Custom architectural woodwork and millwork	19,270	$1,386,000,000
373	337211	Wood office furniture manufacturing	17,330	$1,479,000,000
153	322299	All other converted paper product manufacturing	16,420	$1,680,000,000
138	321219	Reconstituted wood product manufacturing	15,380	$2,081,000,000
144	321992	Prefabricated wood building manufacturing	15,750	$1,061,000,000
140	321912	Cut stock, re-sawing lumber, and planing	14,920	$1,258,000,000
371	337125	Other household non-upholstered furniture manufacturing	140	$11,000,000
135	321114	Wood preservation	9,780	$1,392,000,000
146	322110	Pulp mills	6,220	$1,206,000,000
		Totals	1,032,100	$103,599,000,000

2.8.1 Forest Products Industry Report

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, i.e., 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, i.e., more than a million square miles, covered by forests in the United States. Almost 70% of the forested acreage in the United States is timberland that produces wood that is suitable for industrial and commercial use. About 90% of this land is privately owned. The southern region of the U.S. has about 40% of this timberland, and the northern and western regions have about 32% and 28%, 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 to be a valuable offset for greenhouse gas emissions. The U.S. Forest Service estimates that these systems offset 15% of all emissions.[70]

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. Also, this industry generates and uses more renewable energy than any other industry in the country.

The U.S. has ample forest feedstocks and exports the most forest products to China, other North American countries, and European countries, as shown in Figure 26.

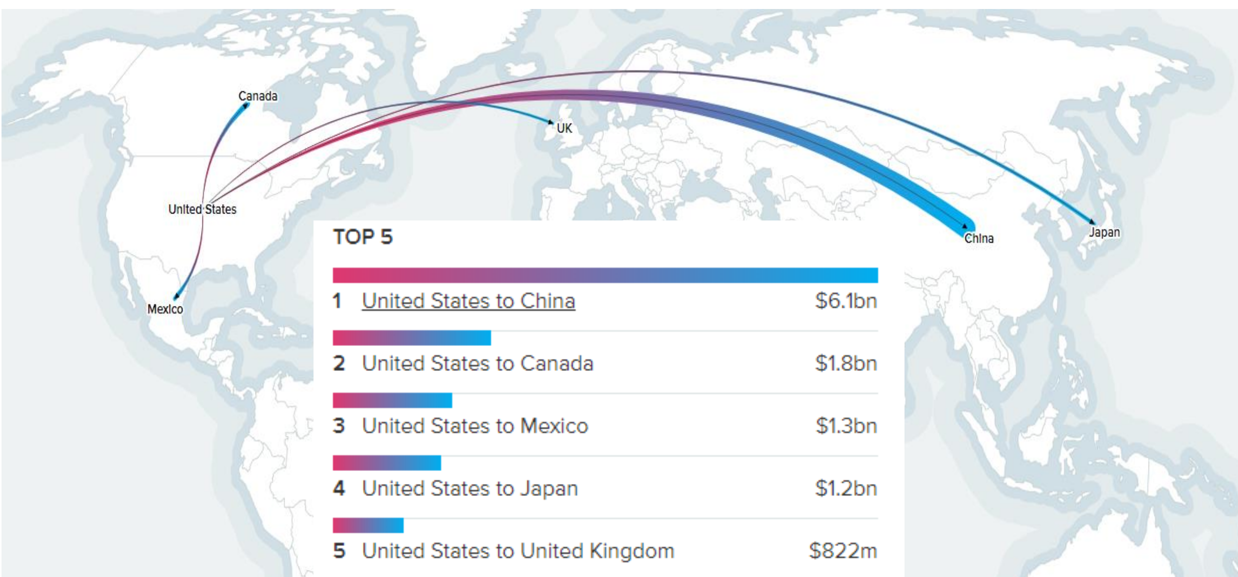

Figure 26: The United States' Forest Product Global Trade Flows in 2016.[71]

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

[71] "U.S. Forest Resource Facts and Historical Trends," USDA Forest Service website, August 2014, accessed May 2018. https://www.fia.fs.fed.us/library/brochures/docs/2012/ForestFacts_1952-2012_English.pdf.

2.8.1.1 Cardboard Box and Container Manufacturing

This is the largest paper-converting industry in the United States, and it 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%. 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%, they are not a huge factor, and manufacturing is moving offshore, thus pushing for consolidation within the industry.

2.8.1.2 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%. The outlook over the next five years is about the same, with a continued annual growth rate of -2.5%. 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% growth in the period from 2018 to 2022.

2.8.1.3 Sawmills and Wood Preservation

This industry relies primarily on both residential and non-residential construction markets, and it 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%. Exports increased at an annual rate of 4.4% 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.

2.8.1.4 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 at the end of 2017, the growth of the paperboard industry slowed to about 0.4%. As the economy strengthens, the outlook is slightly better over the next five years, especially with the influence of online shopping, and the forecast is for an annual growth rate of 1.3%. 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.

2.8.1.5 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%. Exports are not of major importance to this industry.

2.8.1.6 Wood Paneling Manufacturing

This subsector primarily is linked to the construction of homes, and it had strong growth of 6.2% 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%.

Export revenue decreased by 3.8% during the last five-year period, mainly due to the increase in the value of the U.S. dollar.

2.8.2 Case Study: National Wooden Pallet and Container Association

In a recent interview with Patrick Atagi, Vice President for Advocacy and External Affairs at the National Wooden Pallet and Container Association (NWPCA), our team learned how prolific wooden pallets are in the global supply chain and how they also promote the biobased products industry through participation in the USDA's BioPreferred Program. Mr. Atagi has a long history of working at agriculture-related organizations, including the U.S. Apple Association, United Fresh Produce Association, DuPont, and the Department of Agriculture. He has also worked on his 500-acre family farm in eastern Oregon, near the Snake River, and has been in the Peace Corps. All of these experiences have prepared him well to be an advocate for the NWPCA.

The wooden pallet industry is an $11.5-billion American success story, with two billion wooden pallets in use every day in domestic shipping and warehousing operations. American products worth about $400 billion are exported annually on wooden pallets. Wooden pallets are an important sustainable and reusable component of the logistics industry. Of the two billion pallets in circulation, 1.5 billion have been remanufactured, and 500 million new pallets are used every year. Pallets may be damaged by a forklift or they may wear out during normal use over a period of time. Remanufacturing pallets involves removing and replacing broken boards and reselling the remanufactured pallets. The largest size pallet is 48" by 40", which is the standard established by the Grocery Manufacturers Association (GMA). About 40% of the market consists of GMA standard pallets.

There are generally three types of pallets produced. First, strong 48" x 40" pallets are mass produced at a reasonable price using highly-efficient manufacturing processes. Second, the industry has existing pallets remanufactured by sending them out to a network of pallet remanufacturers. Third, the industry uses customized pallets that are produced in special sizes. For instance, special-sized pallets must be designed and constructed for windmill blades, heavy equipment, barrels, and many other products that are part of the global logistics economy. Almost 94% of the products that contribute to the U.S. economy are moved from one place to another on a pallet of some sort. There are over 3,000 pallet remanufacturers in the U.S. that recycle the pallets and make them usable again. About 10-15% of the remanufacturers are global companies.

Though pallets can be constructed using a variety of materials including plastic, metal, and corrugated cardboard, 93% of pallets are made using wood. The type of wood used in pallets varies depending on what is most available in the region, and the two major types of wood that are used are Southern yellow pine (softwood pallets) and oak (hardwood pallets). Oak is used because of its strength and extensive availability. Often, oak that is left over from the construction of houses and furniture is used to produce pallets. Because oak is a high-density hardwood, it is ideal for pallets that must haul heavy loads of fragile goods.[72]

Pine is commonly used in pallets because softwoods tend to be more consistent in weight than hardwoods, giving the product a high strength to weight ratio. Softwoods also are easier to dry, which helps prevent contamination from fungi, molds, or pests. Thus, pallets produced with southern yellow pine are ideal for various industries, such as the pharmaceutical, food, and beverage industries, in which the cleanliness of the pallet is very important.

All pallets are made from the core of the tree, which is considered low-grade lumber. The outer part of the tree typically does not have knots and imperfections, and it usually is used for other products, such as furniture and flooring. Other uses of low-grade lumber include railroad ties and foundations that the oil industry can use in muddy conditions when there is no road. The core of the tree is cut into boards that are fastened together, typically with a high-powered fastening tool.

Patrick notes that a significant amount of engineering is required in the design and manufacturing of wooden pallets. The Pallet Design System™ (PDS)[73] is a product specification tool, an engineering design tool, a professional marketing tool, and an educational tool, all of which are part of an easy-to-use software package that was developed for the wooden pallet industry. PDS can evaluate the strength, stiffness, and durability of wooden pallets. The USDA BioPreferred Program recognizes the innovative approach of the PDS. The innovative approach in the PDS has resulted in the design and production of better performing pallets last longer and have lighter weights.

Patrick also recalls that since the PDS was developed in 1984, it has developed a highly respected reputation throughout the material handling industry. When the NWPCA released PDS Version 5.1 in 2013, it marked the 33rd version of PDS over its 29-year history. The major new feature in Version 5.1 was its integration with LoadSync™ software, which also was developed by the Association. The software enhanced the ability of the manufacturers of wooden pallets to communicate with their customers concerning pallet and unit load design information. Each new version of PDS incorporates the latest data, engineering approaches, and technologies that result from NWPCA's ongoing research and development program. Millions of

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72 "Focus on lumber in the wooden pallet industry," Rose Pallet website, July 13, 2016, accessed July 2018. http://www.rosepallet.com/lumber-used-for-pallets/.

73 "An Introduction to the Pallet Design System™," National Wooden Pallet & Container Association website, accessed July 2018. https://www.palletcentral.com/page/PalletDesignSystem.

dollars have been spent on PDS for the development of software and for research to elucidate the relationships between the design and performance of wooden pallets and the entire unit load. The PDS software enables wooden pallet manufacturers to assist their customers in:

- significantly reducing costs
- significantly reducing damage to products that are being transported
- significantly increasing safety throughout the unit load handling system

The USDA Certified Biobased Product label has had and continues to have an important role in promoting the use of wooden pallets. Recently, the HD Pallet Company LLC, a Memphis-based pallet Company, had a customer who was purchasing more than 95,000 pallets per month solely because the pallets were certified by the USDA BioPreferred Program.

2.8.3 Case Study: Procter and Gamble

At P&G, biobased materials are of significant interest in the Company's product development labs. As noted in an earlier case study in this report, P&G is working to develop biobased chemicals in its Fabric Care Division, and the current focus is on Tide purclean™. Additionally, in 2012, the Company partnered with The Coca-Cola Company, Ford Motor Company, H.J. Heinz Company, and NIKE, Inc. to form the Plant PET Technology Collaborative (PTC) whose goal is to accelerate the development and use of biobased PET in their products.

However, another division of P&G is using wood-based lignin and other plant-based raw materials to develop more biobased products. For example, Bounty and Charmin, two P&G brands, are produced from tree pulp. Similarly, P&G's Tampax products are produced primarily from sustainably grown cotton, a biobased material which can be traced back to the gin, the supplier, and the states where it was grown. Tampax's Pure and Clean products are made of 100% cotton, and they are free of chlorine bleach, dyes, and fragrances. In addition, the applicators are 90% plant-based since they are produced from a biobased polyethylene plastic made from a Brazilian sugar cane feedstock. P&G is continuing to look for other new materials that are biobased for several of the Company's products.

Dr. Anne Weisbrod is a principal scientist in the Global Product Stewardship Program, which is made up of 600 P&G employees who are responsible for regulatory compliance and affairs and human safety assessments. The goal of this Program is to ensure that products are safe, and there also is an increasing focus on their environmental impacts and the best ways of disposing of products at the end of their useful lives, whether by composting, biodegradation, or other means. Dr. Weisbrod's job is closely related to pollution prevention, and biobased products are important in that they may have less adverse environmental impacts at the end of their useful lives than many other raw materials and products. Dr. Weisbrod's team works on environmental risk assessments to determine how products are disposed and their resulting impact on the environment. They consider questions such as: Does the product go into a landfill or an incinerator? Is it biodegradable but disposed in a manner that prevents it from decomposing (e.g., in an oxygen-restricted environment, such as in water)? Can it be made biodegradable before it goes into a river or a landfill? These are all important questions that involve studying how materials are disposed of, and environmental toxicologists spend a lot of time seeing answers for these questions.

Dr. Weisbrod noted that, unfortunately, she sees a lot of "greenwashing. Dr. Weisbrod indicated that she finds this to be very frustrating because, for example, consumers might think that buying a recyclable or compostable diaper helps the environment, and brands also encourage that thinking in their promotional advertisements. However, Dr. Weisbrod remarked that these brands fail to make consumers aware that companies are not allowed to recycle diapers because of the potential of transferring pathogens, and there are very few industrial compost sites in the United States. So, ultimately, such consumer products end up in the landfill rather than being recycled or composted. Dr. Weisbrod contended that companies should be more responsible in making claims about the environmental impact of their products at their end of life.

Additionally, she emphasized that companies should be consistent with the FTC Green Guides,[74] which are designed to help marketers make environmental claims that do not mislead consumers.

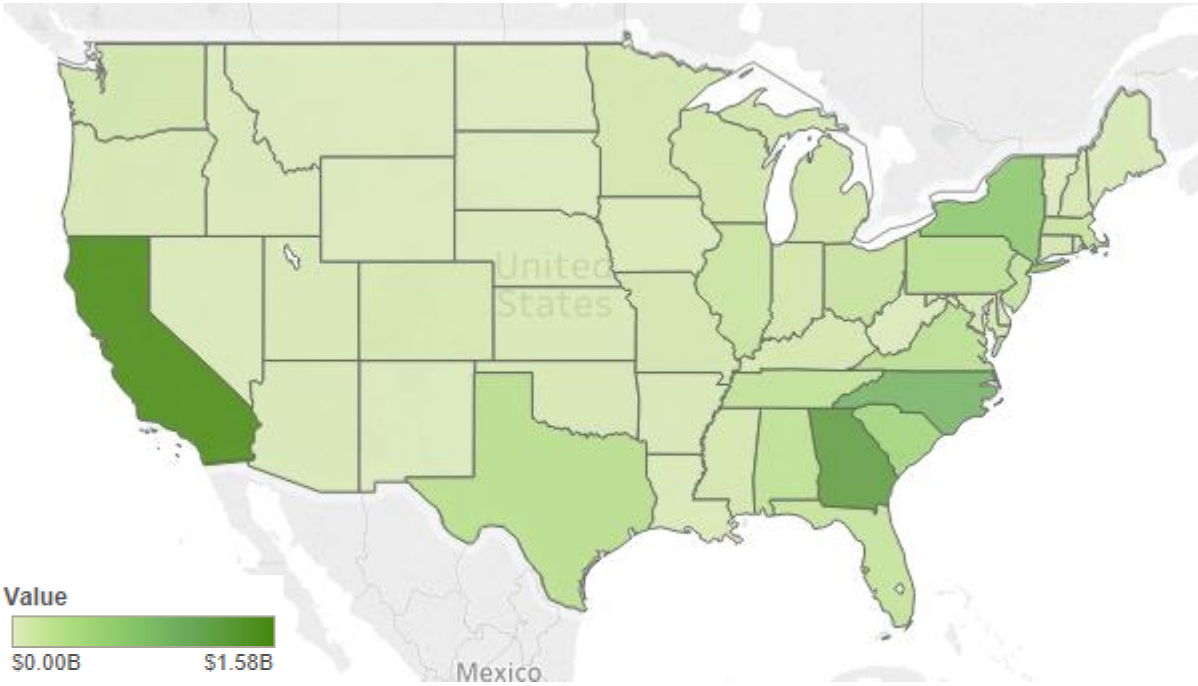
One of the challenges identified by Dr. Weisbrod's team is that internal consumer polls suggested that many consumers have no idea what a biobased product is. For example, with biobased tampons, consumers often have no sustainability benchmarks. For tampons, the primary concerns of consumers are whether they are safe to use and whether they work effectively. A third concern is their impact on the environment after disposal. In general, research has shown that 75% of consumers will not accept tradeoffs in performance or cost for environmental impact. Thus, a product first must be safe, effective, and affordable, and, only then, will most consumers choose a product based on its environmental attributes.

The primary cost driver in producing a consumer product is the cost of the materials, which, in turn, is determined by the prices of the feedstocks. Thus, cost is the single biggest challenge in diversifying the sources of feedstocks. Recently, P&G was successful in encouraging one of its suppliers to work with the National Renewable Energy Laboratory (NREL) of the Department of Energy, and this supplier had some success in converting lignin into biobased plastic materials. Lignin is a waste product from the manufacture of paper, and it is often burned as waste. Staff members at NREL were interested in determining whether lignin could be converted to other materials. This recent development resulted in an affordable, actionable system for the manufacturing process of lignin.

In response to the question concerning what could be done to improve the growth of biobased material applications, Dr. Weisbrod suggested 1) making biobased products and materials more affordable and 2) increasing consumer education and awareness. Regarding affordability, Dr. Weisbrod suggested that biobased materials would be used across a wider variety of consumer products if they were less costly. Additionally, she noted that less costly raw materials would result in less costly finished products. Dr. Weisbrod contented that consumers would choose to purchase a product with better environmental attributes if there were no price differential. Regarding consumer education, Dr. Weisbrod remarked that consumers are often misled by incorrect or unclear environmental claims made by companies. She went on to note that the example of a compostable or recyclable diaper helps to illustrate this issue. Consumers may be misled about the environmental impacts of a compostable or recyclable diaper because they do not realize that a used diaper cannot be recycled and is unlikely to be sent to a composting facility, and instead, a better product attribute for a diaper might be its use of biobased raw materials. Dr. Weisbrod asserted it would be beneficial for USDA and other agencies to provide consumers with education on the environmental attributes of products.

[74] "Green Guides – Environmentally Friendly Products: FTC's Green Guides," Federal Trade Commission website, accessed July 2018. https://www.ftc.gov/news-events/media-resources/truth-advertising/green-guides.

2.9 Textiles



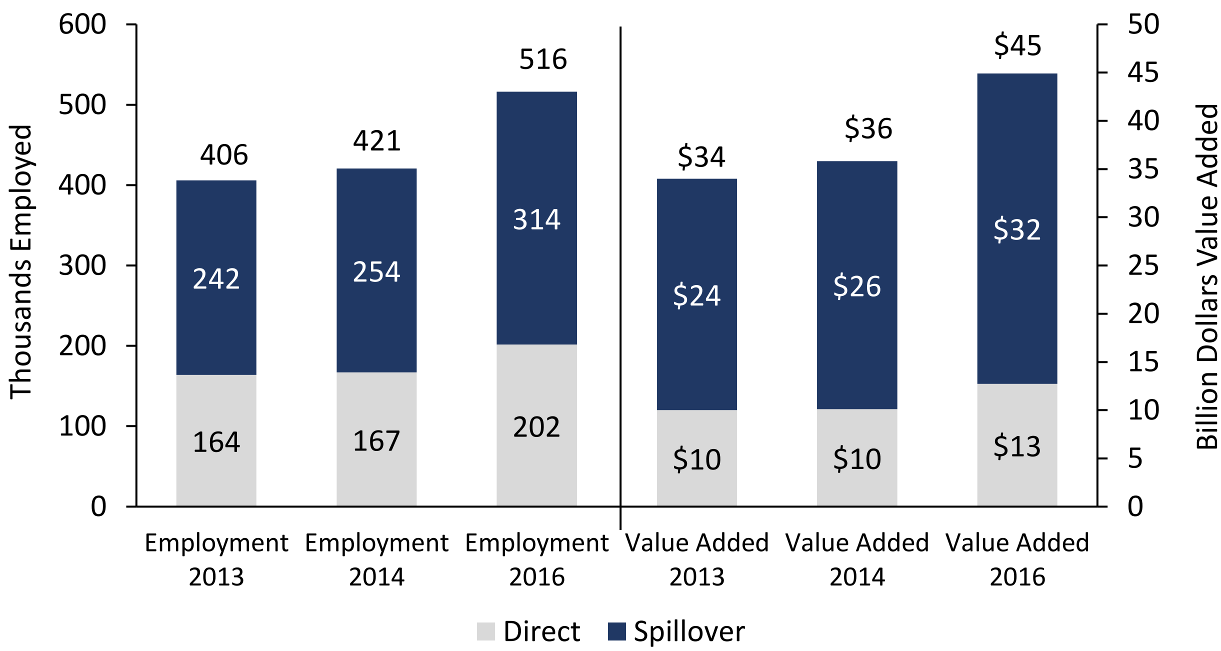


Figure 28: Total Value Added Contributed by the Fabrics, Apparel, and Textiles Products Industry in Each State and the District of Columbia in 2013.

Figure 29: Biobased Textile Contribution to Employment and Value Added in 2013, 2014, and 2016.

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

Major U.S.-Based Firms[75]
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 2016: $45 billion
Exports value added to the U.S. Economy in 2016: $9.0 billion
Type SAM Economic Multiplier in 2016: 3.53

Employment Statistics
Total number of Americans employed due to industry activities in 2016: 516,000
Total number of Americans employed due to industry activities supporting exports in 2016: 108,000
Type SAM Employment Multiplier in 2016: 2.56

Table 10: 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	26,200	$705,000,000
119	314110	Carpet and rug mills	16,700	$1,379,000,000
123	314999	Other textile product mills	19,500	$994,000,000
128	31523	Women's and girls' cut and sew apparel manufacturing	15,300	$1,105,000,000
112	31311	Fiber, yarn, and thread mills	16,100	$953,000,000
113	313210	Broadwoven fabric mills	13,300	$1,041,000,000
127	31522	Men's and boys' cut and sew apparel manufacturing	14,500	$795,000,000
117	31331	Textile and fabric finishing mills	12,800	$974,000,000
121	31491	Textile bag and canvas mills	13,800	$823,000,000
120	31412	Curtain and linen mills	11,700	$833,000,000
129	31529	Other cut and sew apparel manufacturing	7,500	$385,000,000
115	313230	Nonwoven fabric mills	8,300	$1,026,000,000
130	31599	Apparel accessories and other apparel manufacturing	7,400	$356,000,000
124	31511	Hosiery and sock mills	3,100	$134,000,000
114	31322	Narrow fabric mills and schiffli machine embroidery	3,900	$200,000,000

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

118	313320	Fabric coating mills	3,900	$415,000,000
116	31324	Knit fabric mills	3,300	$219,000,000
122	314991, 314992	Rope, cordage, twine, tire cord and tire fabric mills	3,300	$321,000,000
125	31519	Other apparel knitting mills	1,100	$75,000,000
		Totals	201,700	$12,733,000,000

Textiles Industry Report

2.9.1.1 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% 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%. 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 U.S. Environmental Protection Agency (EPA) has 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 (EPA). 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.

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 2016. The estimated petroleum savings from the production and use of biobased products were up to 9.4 million barrels of oil in 2016. 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.[76]

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

3.3 Objectives and Methodology

The production and use of biobased products have the potential to reduce GHG emissions and the use of petroleum.[77] 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 0 to 100% range of the reductions of GHG emission and petroleum use was used and compared to the petroleum-based alternatives. A 0% reduction would indicate no difference compared to petroleum-based

[76] Carnegie Mellon University Green Design Institute, "About the EIO-LCA Method", *Carnegie Mellon University Green Design Institute*, http://www.eiolca.net/Method/index.html.
[77] 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.

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

Only the biobased chemicals, biorefining, and biobased plastic bottles and packaging sectors were considered since 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. The production of enzymes was used as an example because it is difficult to identify the chemicals or products that enzymes directly replace, whereas biobased plastics are 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.[78] These additional categories of impacts are important to consider, and they are acknowledged here, but 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.

Since each biobased product and production process will produce different environmental impacts, in this work, we 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.[79] The economic data used in the environmental analysis were based on 2014 United States' 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 30 and 31, respectively. The results of the EIO-LCA model were generated in terms of kg CO_2 equivalents and TJ 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

[78] 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.
[79] 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*, http://www.eiolca.net/Models/index.html.

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% compared to the use of petroleum-based chemical production methods, which corresponds to 7.6 million barrels of oil.[80] The biorefining industry that produces biobased chemicals is reported to use 80% less petroleum than traditional refineries, resulting in a petroleum savings of as much as 462,000 barrels of oil.[81] The potential amount of petroleum use avoided by the biobased plastic bottles and packaging sector was the lowest of the three sectors we examined. Using data from Yu and Chen and Harding et al., we 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.[82, 83] 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.[84] This previous estimate corresponds to a 26% 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% appears to be a reasonable and conservative number**.**

[80]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.
[81]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.
[82]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.
[83]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.
[84]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.

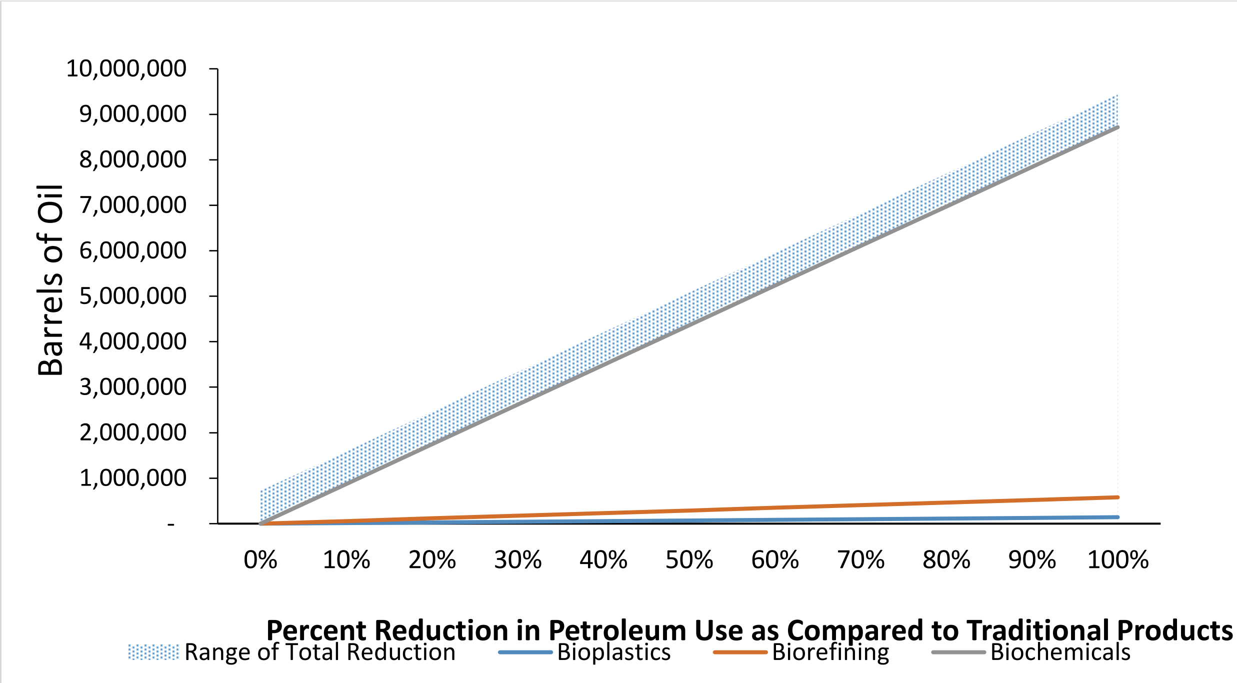


Figure 30: Potential Petroleum Use Reductions by Biobased Products Manufactured in the United States with a Range of 0% to 100% Reduction in Petroleum Use as Compared to Non-Biobased Product Alternatives. Note: assuming a heating value of 6.077 MMBTU per barrel of oil.

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 12.7 million metric tons of CO_2 equivalents in 2016 assuming a conservative 60% reduction of fossil fuel use. The potential avoided GHG emissions for each sector grouping are shown in Figure . Since the biobased chemicals sector is the largest of the three sectors, it has the highest potential to reduce GHG emissions due to the higher volume of sales. Cherrubini and Ulgiati estimated that biobased chemicals produced from switchgrass at a biorefinery reduced GHG emissions by 49% compared to petroleum-based chemicals, which corresponds to approximately 8.6 million metric tons of CO_2 equivalents per year. The biorefining sector, which has less industrial output than chemical production, has a lower potential to offset GHG emissions. With the same percent reduction of 49%, biorefining has the potential to offset as many as 1.0 million metric tons of GHG emissions per year.[85]

[85] 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.

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 decrease in GHG emissions compared to petroleum-based plastics, and Harding et al. reported a 65% decrease compared to petroleum-based plastics.[86, 87] When considering these two percentage reduction in GHG emissions, the reductions from biobased plastics could correspond to taking 239,000 and 194,000 metric tons of CO_2 equivalents for the 65% and 80% reductions, respectively.

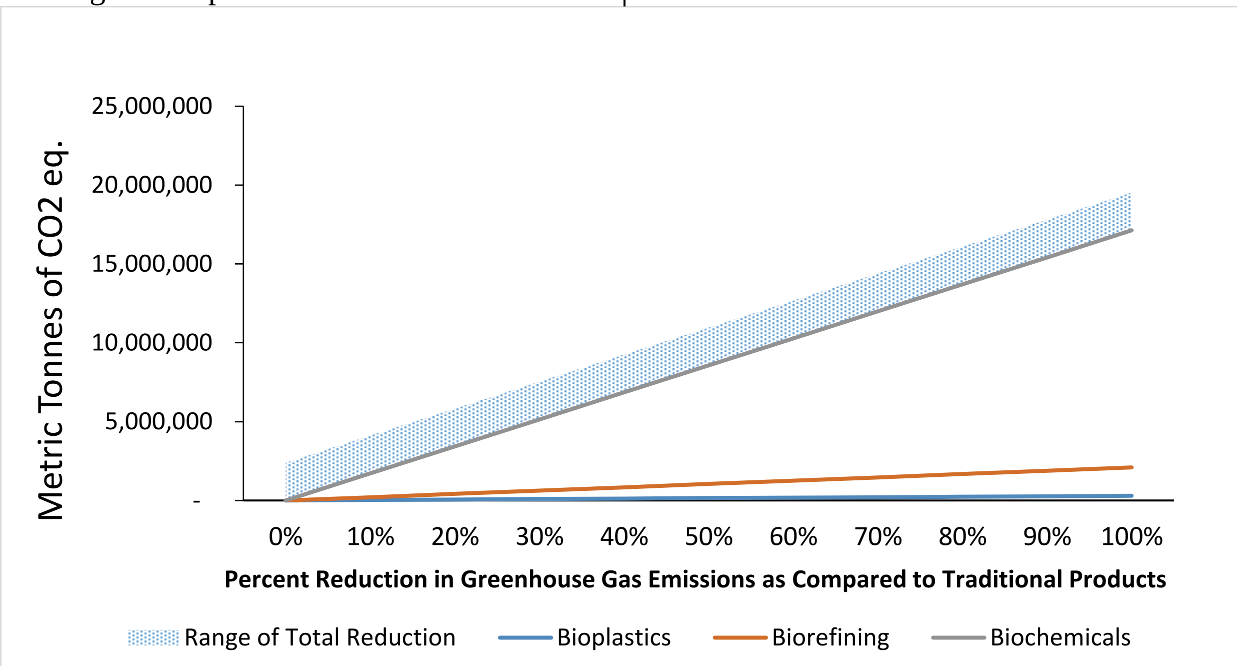


Figure 31: Potential Reductions in Greenhouse Gas Emissions by Biobased Products Manufactured in the United States with a Range of 0% to 100% Reduction in GHG Emissions Compared to Non-Biobased Product Alternatives.

3.7 Limitations

While the EIO-LCA model is useful in many regards, it 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, we 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

[86] 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.

[87] 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.

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.[88, 89, 90] 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 fossil fuels and the associated greenhouse gas emissions.[91] 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.[92, 93, 94]

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),

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[88] Man - Made Cellulosic Fibres (1968). Monopolies and Mergers Commission (UK).
[89] 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.
[90] Shen et al. (2009). Li Shen, Juliane Haufe, Martin K.Patel, 2009, Product overview and market projection of emerging biobased plastics, Universiteit Utrecht
[91] 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.
[92] 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.
[93] 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.
[94] 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.

Nowicki et al. (2008), Pawelzik et al. (2013), and Daystar (2015.).[95, 96, 97, 98]

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 compare biobased polymers and various petrochemical polymers; however, the results can be very 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.[99, 100] 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 we 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.[101] The research that 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.[102]

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.

[95] OECD (2010). OECD, 2009, The Bioeconomy to 2030, Designing a Policy Agenda, www.oecd.org/publishing/corrigenda
[96] Nowicki, P., Banse, M., Bolck, C., Bos, H., Scott, E., "Biobased economy: State-of-the-art assessment," The Agricultural Economics Research Institute, February 2008.
[97] 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.
[98] 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
[99] 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
[100] 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.
[101] 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
[102] 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)

2. Assume that 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.[103]

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.

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. This 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

[103] 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.

when it is first created.[104] End of life LCA modeling also is sensitive to the biogenic accounting methodologies that are used, as discussed earlier.

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

3.8.6.1 Characteristics

In recent years, there has been growing concern for the environmental and health impacts of microplastics pollution and its abundance in the natural environment. It should be noted that biobased materials such as biobased plastics and cotton are often biodegradable and do not create microplastics particles and fibers that persist for long periods of time. This biodegradability of biobased materials will likely help boost the markets for cotton and other biobased biodegradable materials as they don't 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.[105] (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.[106]

3.8.6.2 Biological Interaction

Microplastic ingestion in nature has been observed in a variety of aquatic organisms including bivalves, crabs, shrimps, lugworms, zooplankton, seal, and large filter feeders like whales and some sharks.[107] Ingested microplastic particles have been shown to transfer up trophic levels and translocate to tissues and organs of organisms.[108]

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[104]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.
[105] Wright, S., Thompson, R. and Galloway, T. The physical impacts of microplastics on marine organisms: A review. Environmental Pollution 178 (2013) 483-492.
[106] Andrady, A. The Plastic in Microplastics: A Review. Marine Pollution Bulletin 119 (2017) 12–22
[107] 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
[108] Andrady, A. The Plastic in Microplastics: A Review. Marine Pollution Bulletin 119 (2017) 12–22

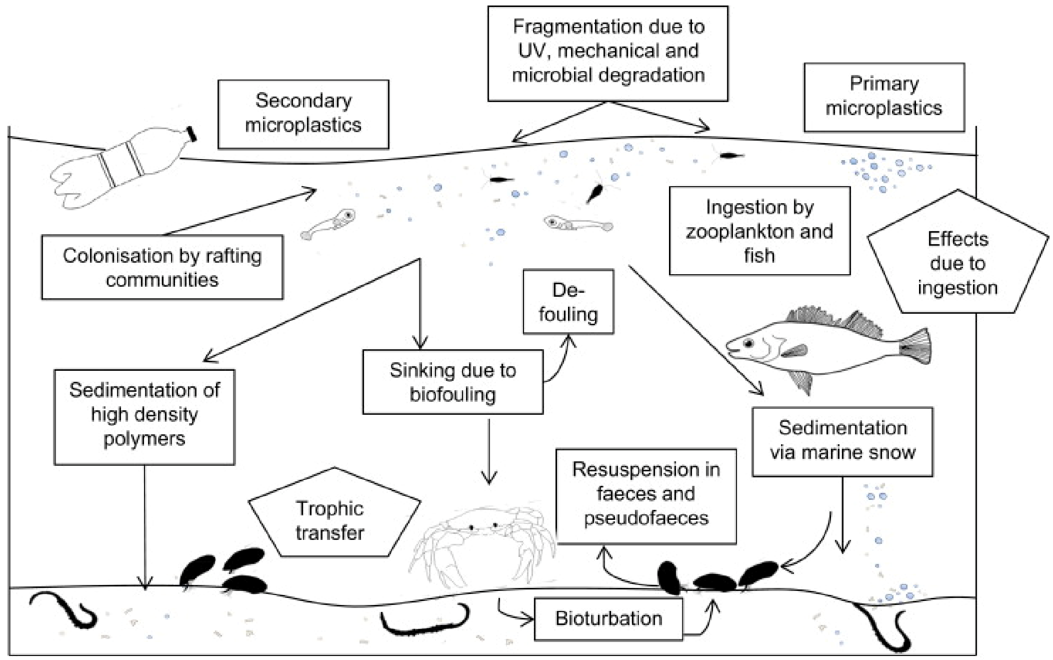

Figure 32: Potential pathways for the transport of microplastics and its biological interactions.[109]

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[109] 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 Federal Biobased Procurement

4.1 Relevant Requirements

The Federal Acquisition Regulations (FAR) contains various requirements that federal agencies track and report their procurement actions relative to biobased products.

Section 9002 of the 2002, 2008, and 2014 Farm Bills requires federal agencies and federal contractors to purchase biobased products in categories designated by USDA. Section 9002 (as codified at 7 U.S. Code §8102) requires agencies to provide data on the number and dollar value of contracts entered into each year that include the direct procurement of biobased products; the number of service and construction (including renovations) contracts entered into each year that include language on the use of biobased products; and the types and dollar value of biobased products actually used by contractors in carrying out service and construction (including renovations) contracts during each year. In addition, the General Services Administration and the Defense Logistics Agency are required to provide information, concerning the types and dollar value of biobased products purchased by procuring agencies.

FAR clause 52.223-2, Affirmative Procurement of Biobased Products Under Service and Construction Contracts, requires services and construction contractors to report their purchases of biobased products to the System for Award Management (SAM).

FAR Subpart 23.103, Sustainable Acquisitions, requires that 95% percent of new contract actions for the supply of products and for the acquisition of services (including construction) require that the products used include six categories of sustainable products, including biobased products.

4.2 Current Reporting Activity

There is no single, centralized federal reporting system for collecting data on federal biobased product procurement. Presently, biobased procurement data are tracked using the following methods:

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 related 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 web site 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.

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.[110] 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.

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 Department of Agriculture, the Department of Defense, NASA, the General Services Administration, and the Department of Energy. 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 Contractor Personnel who are Leaders in biobased product procurement.

The General Services Administration (GSA) has an online tool, the Green Procurement Compilation (GPC) website[111] 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.

3.3 Opportunities for Expanding the BioPreferred Program in Government Acquisition

As noted earlier, public purchasers use the USDA BioPreferred Program's catalog to ensure that their purchases are biobased. Beginning in 2005 with its first designations of six product categories, the program currently has designated 109 product categories, representing approximately 14,000 products that are included in the mandatory Federal purchasing initiative. Federal agencies have several targeted objectives for biobased products. We identified targets for biobased purchases that the federal agencies identified in their 2017 planning process in Table 11.

[110] "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 2018. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/procurement/reports/2017_rcra_report.pdf.).
[111] "Green Procurement Compilation," Sustainable Facilities Tool website, accessed May 2018. https://sftool.gov/greenprocurement.

Table 11: Federal Agency Commitments to Purchase Biobased Products in Fiscal Year 2017.[112]

Agency	Target Contracts	Product Value
Department of Homeland Security	340	$508,006
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	$5,272,256
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	$4,750,000,000
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**	**$453,150,186**

112 "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 2018. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/procurement/reports/2017_rcra_report.pdf.).

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Appendix A

IMPLAN and the Economic Input-Output Model

The Economic Input-Output Model

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

IMPLAN quantifies the economic impacts or contributions of a predefined region in terms of dollars added to the economy and jobs produced (IMPLAN Group LLC 2004).[113] Data are obtained from various government sources, including agencies and bureaus within the Departments of Agriculture, Commerce, and Labor.

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

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

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

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

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

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.[114]

Employment in IMPLAN is represented as the number of both full-time and part-time jobs within an industry that are created to meet final demand. Value added is composed of labor income, which includes employees' compensation and sole proprietor (self-employed) income, other property type income (OPI), and indirect business taxes[115]. OPI in IMPLAN includes corporate profits, capital consumption allowance, payments for rent, dividends, royalties, and interest income. Indirect business taxes primarily consist of sales and excise taxes paid by individuals to businesses through normal operations. Output is the sum of value-added plus the cost of buying goods and services to produce the product.

Key terms:

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

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

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

Economic multipliers quantify the spillover effects, i.e., the indirect and induced contributions. The Type I multiplier describes the indirect effect, which is described by dividing the sum of the direct and indirect effects by the direct effect.[116] 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.

[114] 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.

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

[116] U.S. Department of Commerce Bureau of Economic Analysis (BEA), Interactive Data Application, BEA web site, http://www.bea.gov/itable/index.cfm, accessed April 2015.

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%. Using this method avoided the structural changes that resulted from the customization of the model, and it simultaneously preserved the original relationships in the modeled economy's transactions table.

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

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