An Economic Impact Analysis of the U.S. Biobased Products Industry
A Report to the Congress of the United States of America

Authored By

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Dr. Daystar led the implementation of proprietary cellulosic ethanol production technologies as the Technical Director of Biofuels for Pesco-Beam Environmental Solutions. During his undergraduate education, Chemical Engineering and Pulp and Paper Engineering, Dr. Daystar managed energy efficiency, process control, and quality control studies with Kemira Chemical and MeadWestvaco.

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Executive Summary

This report was prepared for the U. S. Department of Agriculture (USDA) BioPreferred® program and the Congress of the United States of America as mandated in Section 9002 of the 2014 Farm Bill (the Agricultural Act of 2014; P.L. 113-79). The conclusions and recommendations are those of the authors and have not been endorsed by the USDA. The report is a follow-up to the October 2014 report, *Why Biobased? Opportunities in the Emerging Bioeconomy* prepared for USDA.[1] As presented, this report seeks to answer the six following 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 created;
(iv) the quantity of petroleum displaced;
(v) other environmental benefits; and
(vi) 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.

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 "USDA Certified Biobased Product" label have quickly made it one of the most respected and trusted drivers in today's biobased marketplace. Private and public purchasers now look to the USDA BioPreferred program to ensure their purchases are biobased. Beginning in 2005 with its first designations of six product categories, the program now has designated 97 product categories representing approximately 14,000 products on the market today. With the Federal Government spending about $445 billion annually on goods and services, there is an incredible opportunity to increase the sale and use of biobased products as required by federal law. Executive Order 13693, Planning for Federal Sustainability in the Next Decade,[2] increases federal agency accountability for achieving BioPreferred purchasing requirements.

Although there have been several studies of the contribution of the biobased products sector to the global and European economies, this report is the first to examine and quantify the effect of the U.S. biobased products industry from economics and jobs perspectives. 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 include biobased fuels or other energy sources except when analyzing co-products.

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[1] Golden J and Handfield R, "Why Biobased? Opportunities in the Emerging Bioeconomy," USDA BioPreferred® Program website, http://www.biopreferred.gov/BPResources/files/WhyBiobased.pdf, accessed April 2015.
[2] The President, "Executive Order 13693 – Planning for Federal Sustainability in the Next Decade," Federal Register website, https://www.federalregister.gov/articles/2015/03/25/2015-07016/planning-for-federal-sustainability-in-the-next-decade, accessed April 2015.

As detailed in the report, we 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 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 model tracks the way a dollar injected into one sector is spent and re-spent in other sectors of the economy, generating waves of economic activity, or so-called "economic multiplier" effects. IMPLAN uses national industry data and county-level economic data to generate a series of multipliers, which, in turn, 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 contribution analysis is an evaluation of the economic effect of an existing sector, or group of sectors, within an economy. The results define to what extent the economy is influenced by the sector(s) of interest.

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

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

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

As summarized in Figure 1, the total contribution of the biobased products industry to the U.S. economy in 2013 was $369 billion and employment of four million workers. Each job in the biobased industry was responsible for generating 1.64 jobs in other sectors of the economy. Figure 2 shows these numbers in more detail. The 1.5 million direct jobs directly supporting the biobased industry resulted in the formation of 1.1 million indirect jobs in related industries and another 1.4 million induced jobs produced from the purchase of goods and services generated by the direct and indirect jobs. Similarly, the $126 billion in direct sales by the biobased products industry generated another $126 billion in indirect sales and $117 billion in induced sales.

Figure 1: Key Findings of the U.S. Biobased Products Industry in 2013

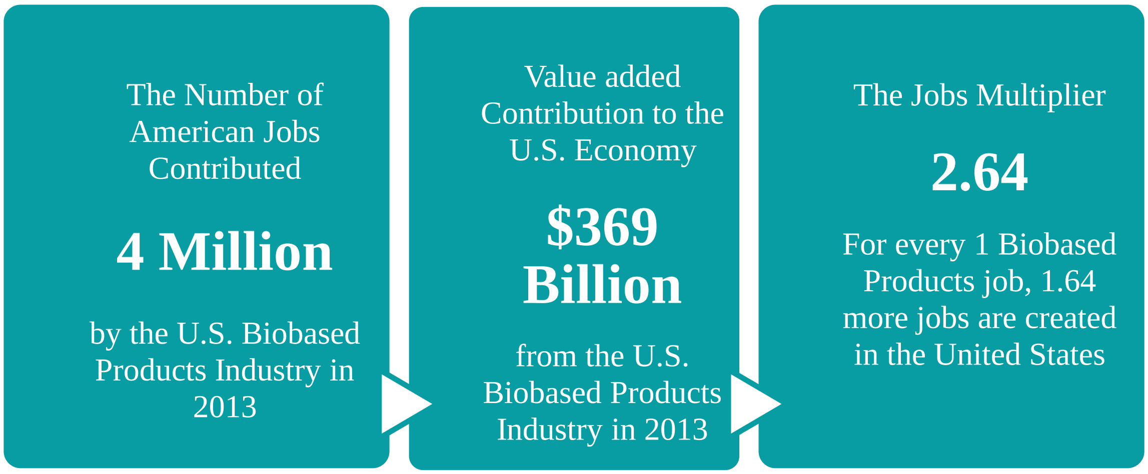
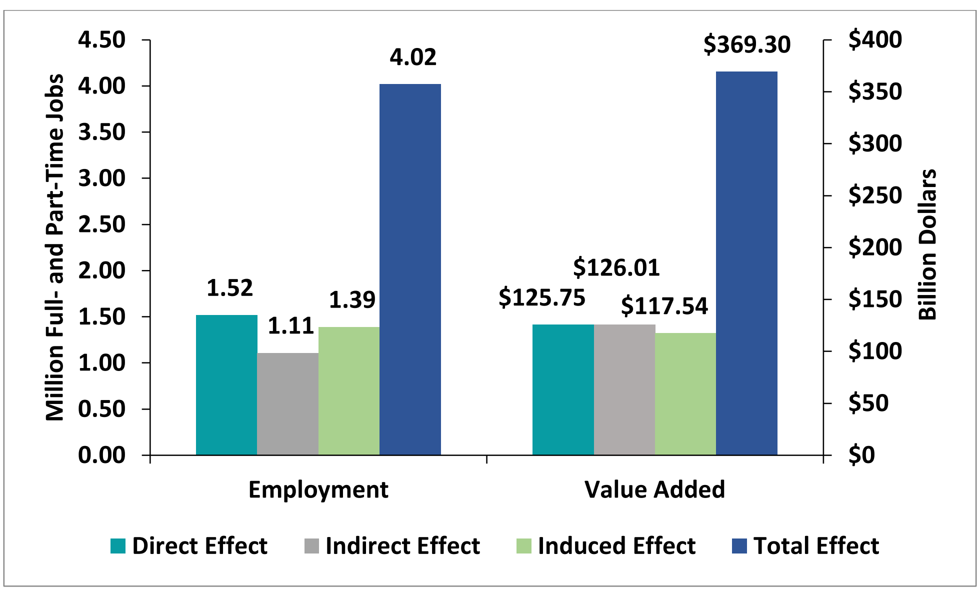
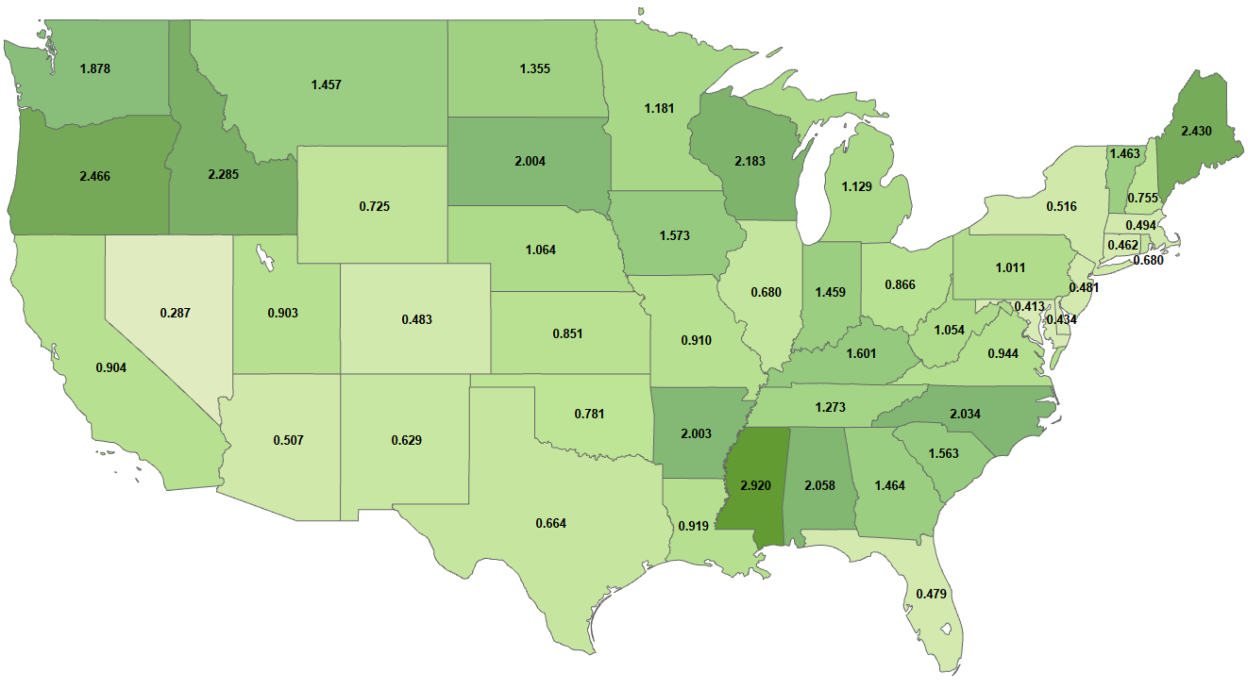


Figure 2: Total Employment and Value Added to the U.S. Economy from the Biobased Products Industry in 2013



We also analyzed the relative employment contribution of the bioeconomy at the state level to its national share of the U.S. economy. We calculated the percent of state employment in an industry divided by the percent employment in the same industry in the United States. This measure is called a location quotient (LQ), and if it is greater than 1.0, it means the state is more specialized in the biobased products industry relative to the U.S. A LQ of less than 1.0 means it is less specialized. Figure 3 shows that the LQs for the contiguous 48 states. States with the greatest concentrations of biobased products industrial activities are Mississippi, Oregon, Maine, Wisconsin, Idaho, Alabama, North Carolina, Arkansas, and South Dakota.

Figure 3: Location Quotient for the Total Biobased Products Industry in 2013



Note: Darker green and higher numbers indicates increased activity at the state level relative to the U.S. in the biobased products industry. For more information, see section II.

Below we provide concise responses to the six questions posed in the 2014 Farm Bill reauthorization.

(i) The quantity of biobased products sold

While there is no database that tracks the "quantity of biobased products sold," the BioPreferred program database includes about 20,000 biobased products. This database contains very few forest products or traditional textile fiber products because these products were only included in the program recently. Therefore, we estimate that the actual number of biobased products is dramatically higher than the number in the BioPreferred program 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 to estimate the total number of individual “units” of biobased products sold are not available. In terms of the dollar value of products sold, direct sales of biobased products in 2013 were estimated to be nearly $126 billion.

(ii) The value of the biobased products

As presented in Figure 2, the value added to the U.S. economy was $369 billion in 2013, the most recent year for which data are available. This estimate compares favorably with a National Research Council estimate of $353 billion for 2012.

(iii) The quantity of jobs created

As shown in Figure 2, the biobased products industry directly employed 1.5 million Americans in 2013 and was responsible for a total of four million jobs throughout the economy.

(iv) The quantity of petroleum displaced

There are two primary mechanisms by which the use of biobased products reduces consumption of petroleum. First, there is a direct replacement of chemical feedstocks that have traditionally been derived from crude oil refineries with chemical feedstocks now being derived from biorefineries. Current estimates of the output of biorefineries used in the manufacture of biobased products is about 150 million gallons per year. The second type of petroleum displacement is through the increased use of natural biobased materials as substitutes for synthetic (petroleum-based) materials that have been in widespread use for many years. An example of this type of petroleum displacement is the use of natural fibers as packing and insulating material as an alternative to synthetic foams such as Styrofoam. We estimate that this second type of petroleum displacement is roughly equal to the 150 million gallons per year estimated for direct replacement. Thus, we estimate that the use of biobased products is currently displacing about 300 million gallons of petroleum per year. This is equivalent to taking 200,000 cars off the road.

(v) Other environmental benefits

While there have been only limited life cycle analyses of biobased product production and disposal, the key environmental benefits of the manufacture and use of biobased products are the reduction in fossil fuel use and associated greenhouse gas emissions and carbon sequestration. Additional analyses regarding the impact of the biobased products industry on water and land use will need to be conducted.

(vi) 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 longer-term opportunities exist that the public and private sectors can undertake to advance the biobased products industry. Those opportunities include creating a biobased products industry consortium and production credits, increasing the visibility of the BioPreferred program's "USDA Certified Biobased Product" label, and expansion of other related USDA programs.

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 these interviews:

- American Chemical Society
- American Cleaning Institute
- BASF
- Bayer
- BioFiber Solutions International
- Biotechnology Industry Organization
- Coca-Cola
- Cotton Inc.
- Green BioLogics
- DuPont
- Dow
- Ford
- John Deere
- Lux Research
- Myriant Corporation
- NatureWorks
- North Carolina Biotechnology Center
- Novozymes
- OfficeMax
- Patagonia
- Penford
- Pistil
- Procter & Gamble
- Seventh Generation
- Society of the Plastics Industry
- Dr. Ramani Narayan, Michigan State University
- Tecnon OrbiChem
- United Soybean Board
- U.S. Department of Labor-Bureau of Labor Statistics
- U.S. Forest Service
- Walmart
- Yulex

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

- Ford
- John Deere
- Penford
- Novozymes
- Coca-Cola
- DuPont
- Patagonia

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 or also can be used in the manufacture of pulp and building material.

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 the material or product as a percent of weight (mass) of the total organic carbon in the material or product. The standard method ASTM D6866 may be 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 manufacture of goods from biological products, renewable resources, domestic or agricultural or forestry material.

Biodegradability: A quantitative measure of the extent to which a material is capable of being 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 all 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.

Bioplastics: Plastics derived from renewable biomass sources, such as vegetable oil and corn starch. In contrast to conventional plastics that utilize petroleum-based products as raw material, biobased plastics utilize biomass, which can be regenerated, as their raw material.

Biopolymers: Polymers produced by living organisms that form long chains by the interlinking of repeating chemical blocks. Common biopolymers in nature are cellulose in the cell walls of plants and polysaccharides such as starch and glycogen.

Bioreactor: A vessel in which a chemical process occurs. This usually involves organisms or biochemically active substances derived from such organisms.

Biorefinery: A facility (including equipment and processes) that converts renewable biomass into biofuels and biobased products and may produce electricity.

Biorefining: Process of production of heat, electricity or fuel 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, other than the principal product, generated as a consequence of creating a biofuel. For example, a by-product of biodiesel production is glycerin and a by-product of ethanol production is distiller's dried grains with solubles (DDGS).

Cellulose: Fiber contained in leaves, stems, and stalks of plants and trees. It is the most abundant organic compound on earth.

Contribution analysis: An evaluation of the economic effect of an existing sector, or group of sectors, within an economy. The results define to what extent 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. 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's sales through employment, value-added, and industrial output.

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

Emission: A waste substance released into air.

Employment: Full and part-time jobs in a sector.

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

Enzyme: A protein or protein-based molecule that speeds up chemical reactions occurring in living things. Enzymes act as catalysts for a single reaction, converting a specific set of reactants into specific products.

Ethanol: Alcohol containing two carbon atoms per molecule with about two-thirds the energy density of gasoline, mostly fermented from corn starch or sugar cane, also known as grain alcohol.

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

Forestry materials: Materials derived from the planting and caring for forests and the management of growing timber. Such materials come from short rotation woody crops (less than 10 years old), sustainably managed forests, wood residues, or forest thinnings.

GTL: Gas to liquid. A refinery process which converts natural gas into longer-chain hydrocarbons. Gas can be converted to liquid fuels via a direct conversion or using a process such as Fischer-Tropsch.

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

IMPLAN: Originally developed by the U.S. Forest Service. The IMPLAN database contains county, state, zip code, and federal economic statistics that are specialized by region, not estimated from national averages, and can be used to measure the effect on a regional or local economy of a given change or event in the economy's activity.

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

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.

Jatropha: Non-edible evergreen shrub found in Asia, Africa, and the West Indies. Its seeds contain a high proportion of oil.

Lignin: A polymer of aromatic alcohols that is a constituent of the cell wall in plants. Lignin stores energy and offers strength to the cell. It is the second most abundant natural polymer in the world after cellulose and serves as a large scale source of biomass.

Lignocellulose: Inedible plant material, mostly comprised of cellulose, hemicelluloses, and lignin. It includes agricultural waste, forestry waste, industrial waste, and energy crops.

Location Quotient: The measure of the concentration of an industry in a state, relative to the national average concentration of that industry.

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

Nanocellulose: Nano-structure cellulose produced by bacteria.

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.

Palm oil: A form of vegetable oil obtained from the fruit of the oil palm tree. Palm oil and palm kernel oil are composed of fatty acids, esterified with glycerol just like any ordinary fat. Palm oil is a widely used feedstock for traditional biodiesel production.

PBS: Polybutylene succinate

PBT: Polybutylene terephthalate

PE: Polyethylene

PEIT: Polyethylene-co-isosorbide terephthalate polymer

PET: Polyethylene terephthalate

PHA: Polyhydroxyalkanoate

PLA: Polylactic acid

PTT: Polytrimethylene terephthalate (from biobased 1,3-propanediol)

PUR: Polyurethane

PVC: Polyvinyl chloride

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 97 designated product categories.

Rapeseed: Rapeseed (Brassica napus), also known as rape, oilseed rape or (one particular artificial variety) canola, is a bright yellow flowering member of the family Brassicaceae (mustard or cabbage family).

Sector: Unique field of industries that is a portion of the U.S. economy defined by North American Industry Classification System (NAICS).

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.

Sub-sector: Field of industries that produce a specialized product.

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

Syngas: A mixture of carbon monoxide (CO) and hydrogen (H_2) that is the product of high temperature gasification of organic materials, such as biomass.

Thermal conversion: Process that uses heat and pressure to break apart the molecular structure of organic solids.

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 plus indirect 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 are generally 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 (OPI), and indirect business taxes (IBT).

- OPI in IMPLAN includes corporate profits, capital consumption allowance, payments for rent, dividends, royalties, and interest income.
- IBT 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.

I. Introduction

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 "USDA Certified Biobased Product" label have quickly made it one of the most respected and trusted drivers in today's biobased marketplace. Visit www.biopreferred.gov for more information.

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 March 2015, there are approximately 20,000 products in the BioPreferred program's database.

Mandatory Federal Purchasing
Private and public purchasers now 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 97 product categories representing approximately 14,000 products that are included in the mandatory federal purchasing initiative. The program offers purchasers of biobased products a universal standard[3] to assess a product's biobased content. By providing a central product registry through its online catalog, accessible at www.biopreferred.gov, the BioPreferred program enables purchasers to find and compare products, such as cleaners, lubricants, and building materials, including carpet, and insulation, from all participating manufacturers; thus, encouraging manufacturers to compete to provide products with higher biobased content.

Voluntary Consumer Label
USDA ushered in the BioPreferred program's voluntary label to the consumer market in February 2011. To date, more than 2,200 products have been certified to display the USDA Certified Biobased Product label and the number of applications continues to increase. With a web-based application process, the BioPreferred program makes it simple for manufacturers to apply for the label and track their application. The program's partnership with ASTM International ensures quality control and consistent results.

[3] American Society for Testing and Materials (ASTM) International, "ASTM D6866-12. Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis," ASTM International website, http://www.astm.org/Standards/D6866.htm, accessed April 2015.

Executive Order 13693, Planning for Federal Sustainability in the Next Decade
With the Federal Government spending about $445 billion annually on goods and services, there is an extraordinary opportunity to increase the sale and use of biobased products as required by federal law. Executive Order 13693, Planning for Federal Sustainability in the Next Decade[4] increases federal agencies' accountability for achieving qualified biobased product purchasing requirements. Federal agencies will be asked to establish annual targets for the number of contracts awarded with BioPreferred and biobased criteria and for the dollar value of BioPreferred and biobased products to be reported under those contracts. Federal agencies also are being asked to ensure that contractors submit timely annual reports of their BioPreferred and biobased purchases.

The Office of Management and Budget has a Sustainability Scorecard to help agencies identify, track, and target their performance for meeting sustainability requirements. BioPreferred is one of the areas that is emphasized. Based on the Sustainability Scorecard data, in FY2013-14, twenty agencies developed biobased purchasing strategies and targets for increasing their level of compliance with federal biobased purchasing requirements. Fifteen of those agencies were able to meet or exceed their targets and seven were able to exceed 90% compliance and share their successful strategies with other agencies so that they may be replicated throughout the Federal Government. USDA presently has 100% compliance with biobased product purchasing clauses in applicable contracts such as construction, janitorial, operations and maintenance, food services, and vehicle maintenance.

A. Congressional Authorization for this Report

Section 9002 of the 2014 Farm Bill (the Agricultural Act of 2014; P.L. 113-79) required USDA to conduct a study and report on the economic impact of the biobased products industry. Specifically, the legislation mandates the following:

Economic Impact Study and Report
In general the study should assess the economic impact of the biobased products industry, including:

(i) the quantity of biobased products sold;
(ii) the value of the biobased products;
(iii) the number of jobs created;
(iv) the quantity of petroleum displaced;
(v) other environmental benefits; and
(vi) 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.

The study and report were managed through the USDA BioPreferred program, which works to increase federal procurement of biobased products and to create market-pull for biobased products through the USDA Certified Biobased Product voluntary label.

[4] The President, "Executive Order 13693 – Planning for Federal Sustainability in the Next Decade," Federal Register website, https://www.federalregister.gov/articles/2015/03/25/2015-07016/planning-for-federal-sustainability-in-the-next-decade, accessed April 2015.

B. About this Report

To date, the availability of data quantifying the biobased products sectors of the economy in the United States has been very limited. 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 sector to understand the challenges and future growth potential for biobased products; we collected statistics from government agencies and the published literature on biobased products, economics, and jobs; 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.[5]

IMPLAN is an economic impact modeling system that uses input-output analysis to quantify the economic activities of an industry in a pre-defined region. IMPLAN quantifies the economic impacts or contributions of the region in terms of dollars added to the economy and jobs produced. Data were obtained from various government sources. These include agencies and bureaus within the U.S. Departments of Agriculture, Commerce, and Labor. When examining the economic contributions of an industry, IMPLAN generates four types of indicators:

- Direct effects: effects of all sales (dollars or jobs) generated by a sector.
- 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 sectors to buy services and goods.
- Total effect: the sum of the direct, indirect, and induced effects.

A Social Accounting Matrix (SAM) multiplier was calculated to represent the overall monetary contribution or jobs created by an industry sector. The SAM multiplier includes direct, indirect, and induced value of jobs. Appendix A describes the IMPLAN modeling framework in detail.

Economic Input/Output modeling utilizing IMPLAN has been used by the Federal Government (U.S. Department of Interior[6] and the U.S. Department of Energy[7]), industry (National Mining Association[8]), and State Economic Development Offices (Aerospace Industry in Georgia[9], and Defense Industry in Arizona[10]).

The greatest limitation of the findings in this report relates to the percentages of biobased sectors within the larger economic sectors, such as biobased chemicals within chemicals.

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

[6] U.S. Department of the Interior, "FY2012 Economic Report," U.S. Department of the Interior website, http://www.doi.gov/ppa/economic_analysis/economic-report.cfm, accessed June 2015.

[7] U.S. Department of Energy, "Economic Impacts of Offshore Wind," U.S. Department of Energy website, http://www1.eere.energy.gov/wind/pdfs/57511.pdf, accessed June 2015.

[8] National Mining Association, "The Economic Contributions of Mining," National Mining Association website, http://www.nma.org/pdf/economic_contributions.pdf, accessed June 2015.

[9] Georgia Department of Economic Development, "Economic Impact Analysis of Georgia's Aerospace Industry," Georgia Department of Economic Development website, http://www.georgia.org/wp-content/uploads/2014/03/Aerospace-Economic-Impact-Study.pdf, accessed June 2015.

[10] Maricopa Association of Governments, "The Economic Impact of Aerospace and Defense Firms on the State of Arizona," Maricopa Association of Governments website, http://azmag.gov/Documents/EDC_2011-06-07_Item-04_The-Economic-Impact-of-Aerospace-and-Defense-Firms-on-the-State-of-Arizona-Final-Report.pdf, accessed June 2015.

To provide conservative estimates of the biobased products sectors, we consistently utilized lower percentages within the ranges we modeled.

Because NAICS codes exclusively for the biobased sectors of the economy do not exist, we developed a novel approach that estimated the percentage of biobased products by sector through interviews with subject matter experts. This included analysts, managers from companies who sell biobased products, and published research to derive estimates that were consistent with these discussions. Limitations of using the IMPLAN model for estimating subsectors of a NAICS code population or a specific geographic region have been noted in other studies.[11]

This report is intended to serve as a platform for greater understanding and tracking the progress of the bioeconomy 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 economic and jobs data with partner government agencies, such as the U.S. Department of Commerce.

[11] Santos XT, Grado SC, Grace LA, and Stuart WB (2011) Effects of Changes in Impact Analysis for Planning Model Industry Sector Data on the Economic Impacts of the Logging Industry in Mississippi. Forest Prod= J 61(5): 390-400.

Section II defines and describes the sectors of the biobased products industry, provides data on economic activity and jobs by sector, shows the relative activity of the biobased products industry by state and sector, and discusses the potential for economic growth in the industry.

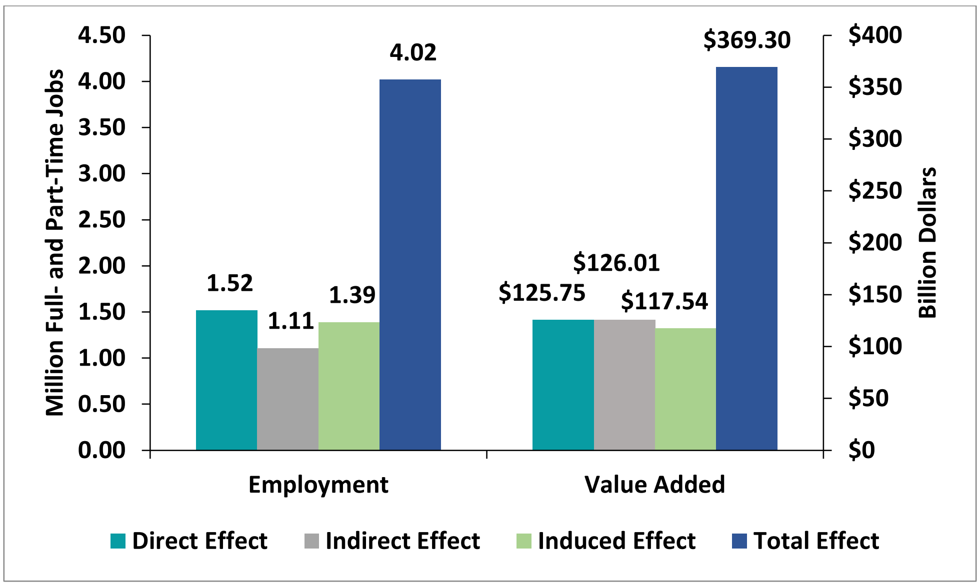
Case studies of seven major corporate leaders that are driving the success and growth of the bioeconomy are interspersed throughout Section II. Section III provides an overview of the biobased products industry and within each of the seven major sectors examined in this report.

Environmental considerations of the biobased products industry are discussed in Section IV. The authors' recommendations are provided in Section V. Appendix A describes the economic modeling framework using IMPLAN. The relative activity of the biobased products industry by sector and by state (location quotients) is listed in Appendix B. Appendix C lists the more than 200 biorefineries in the United States. Appendix D lists the product categories that the BioPreferred program uses to classify biobased products as well as the number of products that are grouped in each. As mentioned previously, 97 of these product categories have been designated for mandatory federal purchasing.

II. Industry Overview

In this section we describe the major sectors of the U.S. biobased products industry. For each sector we discuss the raw materials, processing steps, intermediates, and products introduced into the economy. Data provided include: major U.S. and global firms, total value added to the U.S. economy in 2013 and number of American direct, indirect, and induced jobs generated by the sector. The distribution of economic value added and employment by sub-sector is also provided. Interspersed within the section are case studies and interviews with companies in the forefront of the biobased products industry. Figure 4 shows the effect of the biobased products industry on employment and gross domestic product in the United States in 2013.

Figure 4: Total Employment and Value Added to the U.S. Economy from the Biobased Products Industry in 2013



Major sectors discussed in this section are:

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

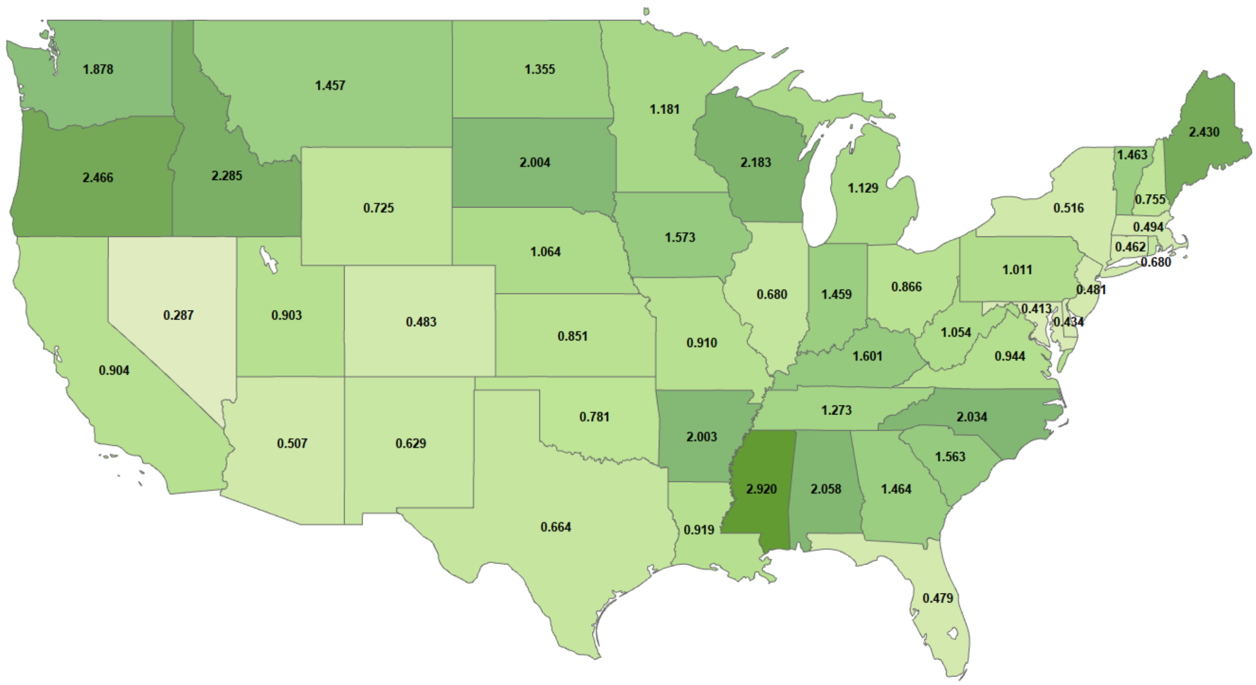
These analyses specifically excluded energy, livestock, food, feed, and pharmaceuticals.

The percentage of products in each NAICS code category that is biobased was estimated using existing literature, interviews with government and industry stakeholders. Data from European research institutes suggest similar figures. Sales of products made by biotechnological processes in 2010 were 91.9 billion Euros (~$104 billion). This compares favorably with the $126 billion in U.S. sales in 2013.

We also include U.S. maps that show the each sector's share of total employment in a region relative to the national share. The measure used to display this is called a Location Quotient (LQ). A LQ greater than 1.0 means the state is more specialized in that sector than the United States on average, while a LQ of less than 1.0 means it is less specialized. The higher the LQ, the greater the tendency to export biobased goods. Figure 5 is a map of the LQs for the total biobased products industry for 2013. A detailed list of LQs by state and sector is provided in Appendix B.

In the subsections that follow, Figures 6, 8, 9, 12, 14, and 15 are national maps of LQs for each of the seven major sectors discussed in the section. Note that the map for the biobased chemicals sector includes the enzyme sector. Tables 1, 3, 4, 6, 8, 9, and 10 show the direct number of jobs and value added for each sector broken out by subsector.

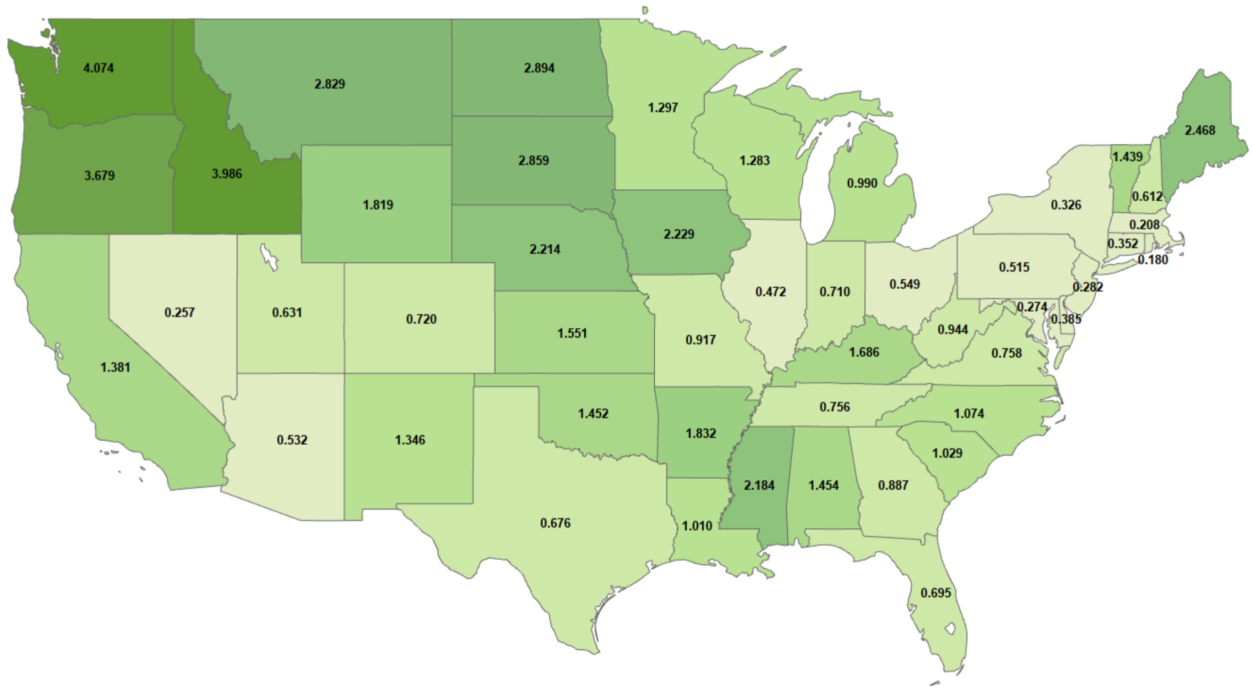
Figure 5: Location Quotient for the Total Biobased Products Sector in 2013



As summarized in Figure 4, the total contribution of the biobased products industry to the U.S. economy in 2013 was $369 billion and employment of four million workers. Each job in the biobased products industry was responsible for generating 1.64 jobs in other sectors of the economy. The 1.5 million direct jobs directly supporting the biobased products industry resulted in the formation of 1.1 million indirect jobs in related industries and another 1.4 million induced jobs produced from the purchase of goods and services generated by the direct and indirect jobs. Similarly, the $126 billion in direct sales by the biobased products industry generated another $126 in indirect sales and $117 in induced sales.

A. Agriculture and Forestry

Figure 6: Location Quotients for the Agriculture and Forestry Sector (2013)



Approximately 2.2 million farms contribute to America's rural economy. About 97% of U.S. farms are operated by families – individuals, family partnerships, or family corporations[12] that, in many cases, are suppliers to companies, such as the major firms listed below.

Major U.S.-Based Firms[13]

Cargill (Minnesota)
Archer Daniels Midland (Illinois)
DuPont Pioneer (seeds) (Iowa)
Land O'Lakes (Minnesota)
Monsanto (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 2013: $29.5 billion

Type SAM Economic Multiplier in 2013: 1.99

Employment Statistics

Total number of Americans employed due to industry activities in 2013: 409,000

Type SAM Employment Multiplier in 2013: 1.68

[12] American Farm Bureau Federation, We Are Farm Bureau, American Farm Bureau Federation website, http://www.fb.org/index.php?action=about.home, accessed April 2015.

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

Table 1. Distribution of Direct Value Added and Employment by Sub-Sector

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	106,180	$6,382,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	77,310	$2,663,000,000
8	111920	Cotton farming	41,640	$3,878,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	13,060	$1,724,000,000
2	111150	Grain farming – only corn included	4,480	<$5,000,000
9	111930, 111991	Sugarcane and sugar beet farming	580	$43,000,000
1	11111	Oilseed farming	230	$157,000,000
		Totals	243,470	$14,848,000,000

Biomass Feedstocks
Biobased products can be manufactured from various biomass feedstocks. Two categories of feedstock and products dominate, i.e., first and second generation. First-generation products are manufactured from edible biomass, such as starch-rich or oily plants. Second-generation products utilize biomass consisting of the residual non-food parts of current crops or other non-food sources, such as perennial grasses. These are generally considered as having a significantly higher potential for replacing fossil-based products. Figure 7 shows examples of the flow of biobased materials from feedstocks to products.

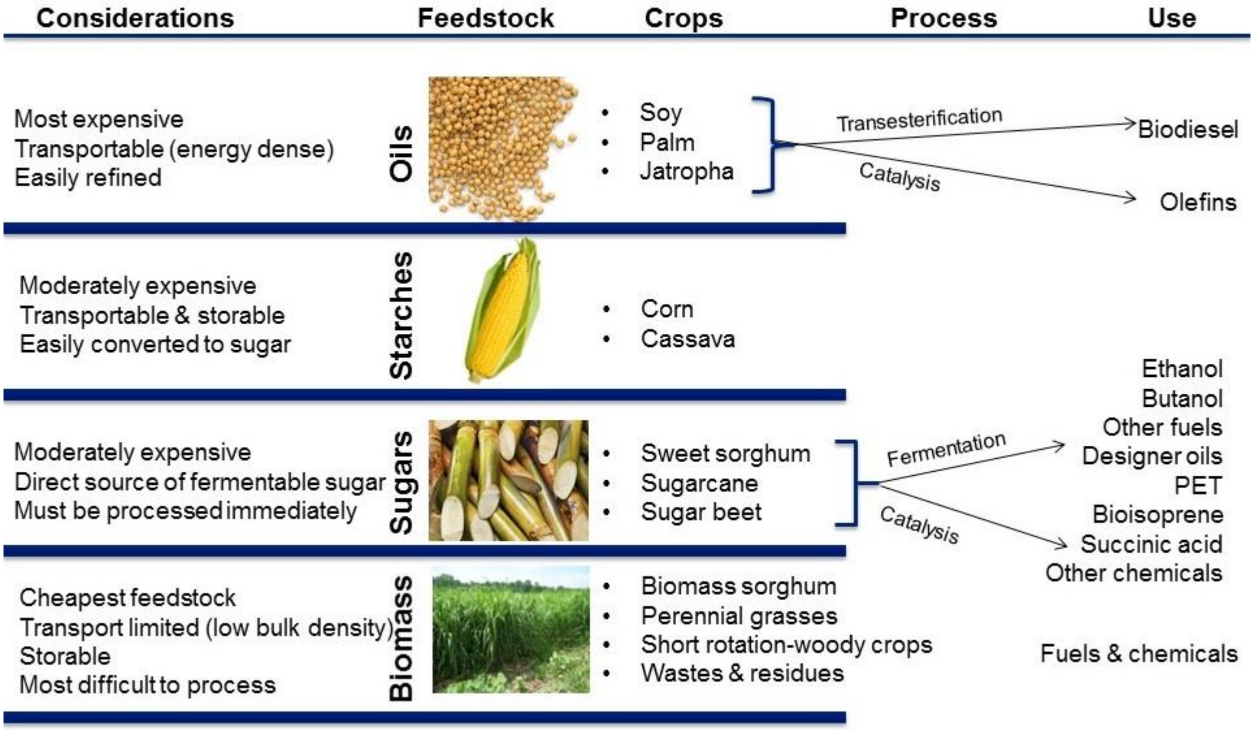
The primary domestic first generation agricultural feedstocks used in the production of biobased products include:

- Corn
- Soy
- Sugarcane
- Sugar Beets

First Generation Feedstocks: Sugar/Starch Crops
The most common type of biorefining today uses sugar- or starch-rich crops. Sugar crops such as sugarcane, sugar beets, and sweet sorghum store chemical energy as simple sugars (mono- and disaccharides), which can be easily extracted from the plant material for subsequent fermentation to ethanol or biobased chemicals.

Starch-rich crops, such as corn, wheat, and cassava (manioc), store energy as starch, a polysaccharide. Starch can be hydrolyzed enzymatically to produce a sugar solution, which subsequently can be fermented and processed into biofuels and biobased chemicals. The processing of many starch-rich crops also produces, as a byproduct, valuable animal feed that is rich in protein and energy.

Figure 7: Considerations Related to Biobased Feedstock



Source: Golden J and Handfield R, "Why Biobased? Opportunities in the Emerging Bioeconomy," USDA BioPreferred® Program website, http://www.biopreferred.gov/BPResources/files/WhyBiobased.pdf, accessed April 2015.Adapted from A. Rath. Presentation at the Biobased Feedstocks Supply Chain Risks and Rewards Conference. Hosted by Duke and Yale Universities. Washington, DC, 2012.

According to the World Economic Forum, in 2010 there were about 400 operational first-generation biorefineries around the world.[14] In January 2015, there were 213 biorefineries in the United States (see Appendix D).[15]

Second-Generation Feedstocks

Lignocellulosic biomass (or simply biomass) refers to inedible plant materials, which consist primarily of cellulose, hemicellulose, and lignin. This biomass represents the vast bulk of plant material, and it includes:

- agricultural waste, such as straw, corn stover (leaves and stalks after harvest), corn cobs (the hard cylindrical cores that bear the kernels of an ear of corn), bagasse (dry dusty pulp that remains after juice is extracted from sugarcane), molasses (thick, dark syrup from the processing of sugarcane or sugar beets);
- forestry wastes, such as harvesting residues;
- fraction of municipal and industrial (paper) wastes; and
- Fast-growing energy crops, such as miscanthus, switchgrass, short-rotation poplar, and willow coppice.

[14] World Economic Forum, "The Future of Industrial Biorefineries," World Economic Forum website, http://www3.weforum.org/docs/WEF_FutureIndustrialBiorefineries_Report_2010.pdf, accessed April 2015.

[15] Renewable Fuels Association, Biorefinery Locations, Renewable Fuels Association website, http://www.ethanolrfa.org/bio-refinery-locations/, accessed April 2015.

By weight, the largest component of plant matter is lignocellulosic material, which is a mixture of cellulose, hemicellulose, and lignin. Properties of lignocellulosic materials are listed in Table 2.

Table 2. Properties of Lignocellulosic Materials

Lignocellulosic Materials	Cellulose %	Hemicellulose %	Lignin %
Coastal Bermuda grass	25	35.7	6.4
Corn cobs	45	35	15
Cotton seed hairs	80-95	5-20	0
Grasses	25-40	35-50	10-30
Hardwood stems	40-55	24-40	18-25
Leaves	15-20	80-85	0
Newspaper	40-55	25-40	18-30
Nut shells	25-30	25-30	30-40
Paper	85-99	0	0-15
Primary wastewater solids	8-15	NA	24-29
Softwood stems	45-50	25-35	25-35
Solid cattle manure	1.6-4.7	1.4-3.3	2.7-5.7
Sorted refuse	60	20	20
Swine waste	6	28	NA
Switch grass	45	31.4	12
Waste papers from chemical pulps	60-70	10-20	5-10
Wheat straw	30	50	15

Source: Dakar M, Katzen International, Inc., "Challenges of Ethanol Production from Lignocellulose Biomass," Katzen International, Inc. website, http://www.katzen.com/ethanol101/Lignocellulosic%20Biomass.pdf, accessed April 2015

Both cellulose and the hemicellulose are chained polymers made up of individual sugar molecules. Cellulose is a long linear chain, while the hemicellulose are much shorter and often have branches. When these chains are attacked through either acid or enzymatic hydrolysis and converted to their constituent sugars, the long cellulose chain splits into glucose. Although cellulose is found in greater proportions than hemicellulose, the relative amounts of each within a plant depend upon the kind of plant and its age. In general, hemicellulose comprises about 20% of a lignocellulosic material. Many commercial fermentation methods ignore this valuable fraction.

Unlike hemicellulose, cellulose is a stable molecule that is difficult to hydrolyze. This difference in stability manifests itself in different reaction rates and different reaction end points. In order to utilize the hemicellulosic component of biomass, a viable method of metabolizing the resulting sugars is needed. Techniques ranging from genetic engineering of yeast and bacteria to environmental acclimation are used to develop strains to make use of hemicellulose.[16]

[16] Arkenol, FAQ's – Regarding Arkenol's Technology, Arkenol website, http://www.arkenol.com/Arkenol%20Inc/faq03.html, accessed April 2015.

Roundwood

Industrial roundwood products include any primary use of the main stem of the tree. This includes pulpwood, sawlogs, and veneer logs, but it excludes residential fuelwood. Timber grown to make wood pulp for paper production is known as pulpwood, and it is usually harvested young, while the trunks are still small in diameter. 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 primarily used in paper production, 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, which were obtained from the pine forests in the southern U.S. Today, these products include biofuels and bioenergy, rayon fabrics, filters, cosmetics, fragrances, pine oils, and many others.

A1. Case Study: Ford Drives Innovation in Soy based Automotive Components

Source: Ford Motor Company

Ford has taken on a commitment to design and build vehicles that are environmentally sustainable, and the company has established several groups that are tasked with thinking about how to drive new solutions that are aligned with sustainable outcomes and that also meet customers' needs for cost, quality, and performance in their vehicles. To achieve this, Ford established a Director of Global Sustainability Integration, Ms. Carrie Majeske, and charged her with "connecting the dots" between design engineers, suppliers, and others in the innovation process. The Director also produces a sustainability report that focuses on all of the company's primary sustainability initiatives. A big piece of this effort is focused on human rights and people's working conditions. This case provides a fascinating insight into an organization that is committed to researching biobased products, and it provides encouraging information concerning how the company's perseverance has paid off.

Ms. Majeske has opportunities to work with many people in the organization, and one of her major contacts is Dr. Debbie Mielewski, who leads the sustainable materials lab at Ford. Dr. Mielewski leads a research lab that works on the next generation of materials that will be integrated into Ford vehicles. In the year 2000, Dr. Mielewski and her colleagues decided to focus on seeking sustainable materials that could replace petroleum-based plastics. Initially, the focus was on improving Ford's environmental footprint, but, since oil prices were very low at that time, there was little interest among designers to do so. The team began exploring soy-based foams, but there were many technical issues, and the team began to address them on a case-by-case basis.

In 2007, the team worked with suppliers to develop a formulation that met all of the durability and requirements for federal vehicle regulations. The material replaced up to 12% of poly-oils with soybean oil. During this period, oil was priced at $165 per barrel, and more people became interested in the Laboratory's work. The decision was made to integrate the material into the Ford Mustang. Dr. Mielewski worked with the United Soybean Board (USB) to purchase excess stocks of soybeans, and, eventually, the technology was used in every vehicle in North America. The technology is being shared with other manufacturers who could begin to apply soy-based foam in their products, including mattress, child seat, and packaging manufacturers.

The next big success was the focus on replacing glass fibers with natural straw-based fibers, and this work was undertaken in conjunction with the Canadian government. The Canadian government is motivated to fund university and supplier collaborations to use straw polypropylene in the Ford Flex. This product is made from waste products consisting of the remains from wheat products after the wheat is removed. The fiber is sequestered and used to reinforce the bin that is in the driver's compartment, as it replaces the glass fiber perfectly. Tier 2 suppliers in the supply chain use the material in processes that mold the material into the bin. Prior to this, this waste material was not used for any purpose at all, and farmers usually burned it after the wheat was removed.

Wheat straw is harvested at six farms in Ontario, Canada, where both the supplier and the Ford plant that uses the product are located. Thus, the carbon footprint for shipping the product also is minimized. This has been a learning experience that the Ford design team is seeking to replicate. The importance of designing supply chains for innovative new materials is not lost on the research and development team. The team is also seeking to conduct life cycle analyses for soybean farmers. Other materials include dandelions with a Russian university, latex in a root that may replace rubber, mustard seed oil for foams and urethanes, and other innovative sources of materials.

To date, Ford has used more than a million pounds of soybeans, with an estimated reduction of more than 20 million pounds of CO_2. Soybean-based cushions save an estimated five million pounds or more than 17,000 barrels of petroleum annually as well. Today, over three million Ford vehicles have some soy foam in them.

Ford’s suppliers are also acutely aware of the soy foam initiative and the push for the development of biobased products. All of Ford’s suppliers in this particularly unique material chain (Lear, JCI, and Woodbridge) have very developed environmental initiatives and policies around sustainable corporate directives. In this sense, Ford’s proactive stance is driving activity down the entire supply chain, and it is rewarding suppliers who drive innovation. Other Tier 2 suppliers include Dow, Huntsman, and Weyerhaeuser. Their products have won awards from the Society of Plastic Engineers for the wheat-based bins, which are much less dense but perform just as well as glass fiber.

The other fascinating part of this story is how Ford’s success is breeding collaborative new designs and innovation with other organizations in diverse industries. For example, a group of organizations, including Nike, Coca-Cola, Heinz, and Procter & Gamble, is working on developing plant-based polyethylene terephthalate (PET) materials, and Ford’s collaboration with this group has been highly productive due to the non-competitive nature of the collaboration. The groups have been encouraged to meet and share how their research processes in biobased products work, thereby allowing them to learn from each other.

In this manner, partnerships have been encouraged. Dr. Mielewski related a recent instance in which she was meeting with a group of researchers from Heinz, and the conversation was focused on waste products. A Heinz engineer mentioned that Heinz processes billions of pounds of tomatoes and is left with massive amounts of tomato fiber waste for which the company has no use. Subsequent to this conversation, Ford received shipments of samples that included fibers, stems, and tomato seeds, and these waste products were ground and mixed into some plastic components. The initial pilot trials have been successful. The groups are working together on achieving 100% biobased PET, and they are considering the use of other bio-waste streams for product development.

Other areas of vehicles also are being targeted for potential biobased material applications. Today, only about one percent of the interiors of vehicles are biobased. However, there are about 300 pounds of polymers in a typical 5,000 pound vehicle, and this provides an enticing target for the use of additional biobased materials. Cost and availability constraints are issues that must be considered further with respect to these parts. There also are opportunities to use soy-based foam in other industries, such as aerospace construction, farming equipment, and others. Government support for aligning different industries who could use the materials is another element that would help to ensure that the demand for these products will increase in additional industries.

A2. Case Study: Biopolymers in John Deere Tractors

John Deere has a long history of close ties with the farming community and is a major producer of tractors, harvesters, and planting equipment. Key themes that form the requirements for use of biopolymers include the need to support farmers (customers), emphasizing the need through a supply chain "pull" to initiate commercialization, emphasizing internal adoption through rigorous cost parity comparisons, the opportunity for the market to use the John Deere brand name in marketing, and the commitment to a green policy, including "using recycled or renewable [materials] wherever feasible."

Ms. Laurie Zelnio, Director of Safety, Environment, Standards and Energy/Product Sustainability notes that "the challenge in adopting biopolymers in our products is not the engineering and technical aspects, but in the economics of the feedstocks. And the challenge also involves comparing the sustainability solution to the alternative feedstock already being used. It requires that we consider the entire product footprint, and take a broad look at the impact. When you look at biopolymers in this light, it is not always intuitive what the different alternatives will look like. Material selection is a key element of Design for the Environment, a program that we emphasize throughout all of our businesses at John Deere. We have developed a Material Selector tool that assists engineers to make better product life cycle and sustainable decisions. For example, steel is very good for recycling, whereas some resins are not, so we have to look at the entire system over the product life cycle. But I do think that time is on the right side of biofeedstocks, and their time has indeed come."

Jay Olson, Manager of Materials Engineering and Technology in the John Deere Technology Innovation Center, has a key role in helping to make the case for biobased polymers. He is keenly interested in selecting and finding more options that are viable for agricultural products that are based on performance, economic cost advantage, and promoting renewables and recycled materials. Deere, like many other companies, is seeing more and more bio-components, resins, and substitute resins that are better than the conventional products derived from petrochemicals. This, in large part, is due to the growth of the green chemistry movement promoted by the American Chemical Society.

The Materials Engineering staff serves an important role as materials consultants to the engineering and design functions at John Deere. "We help our engineers develop their design and manufacturing and sourcing plans through design and materials standards. When design engineers select a material, they select them from an approved set of preferred materials and standards, and [they] must follow the John Deere design standards established. We get involved when they need help. We have plastics engineers, metallurgists, and paint engineers that work with them. Because Deere sources a large percentage of our parts, by definition we have to work with our suppliers on these elements. Parts manufactured internally at Deere include drive train assemblies, which are critical to our products. As such, we have to work closely with our supply base as we identify new material trends for the future, as they are the conduit for new technologies introduced into the design cycle."

Soy based panels were one of the first components in which petrochemical-based plastics were replaced by biobased polymers. In the 1990s, the USB approached Deere through its marketing team and asked the company to work with its engineers to develop a soy-based oil polymer, the prototype of which was developed from an epoxidized polymer by a team at the University of Delaware that was funded by the USB. The commercialization of the product took place at Ashland Chemical, which was already producing a soy-based chemical that could be altered and combined with corn-based ethanol for the unsaturated component. Other suppliers involved in the production of the parts included Continental Structural Plastics and Ashley Industrial Molding. The panels consisted of feedstocks that were half soy oil and half corn ethanol, and, in 2001, they were used initially in North American Combine's small styling panels (shown at the start of this section); later, in 2002, their use was expanded to all of North American Combine's styling panels.

As the program expanded, in 2004, the soy panels were introduced into the hoods of the 5000 Series small agricultural tractors (shown below).

One of the reasons that soy-based panels were put into use so readily was that there were strong technical and commercial business cases. The panels went into production rapidly, and initial tests showed that it was easier to paint the biobased panels than the original, petroleum-based polyester panels. This created a net cost reduction for the product because the new part took less paint. This is an important criterion for the use of all biobased components for industrial manufacturing. If these new parts cost the same or less than the original parts, the likelihood that they will be used will increase significantly.

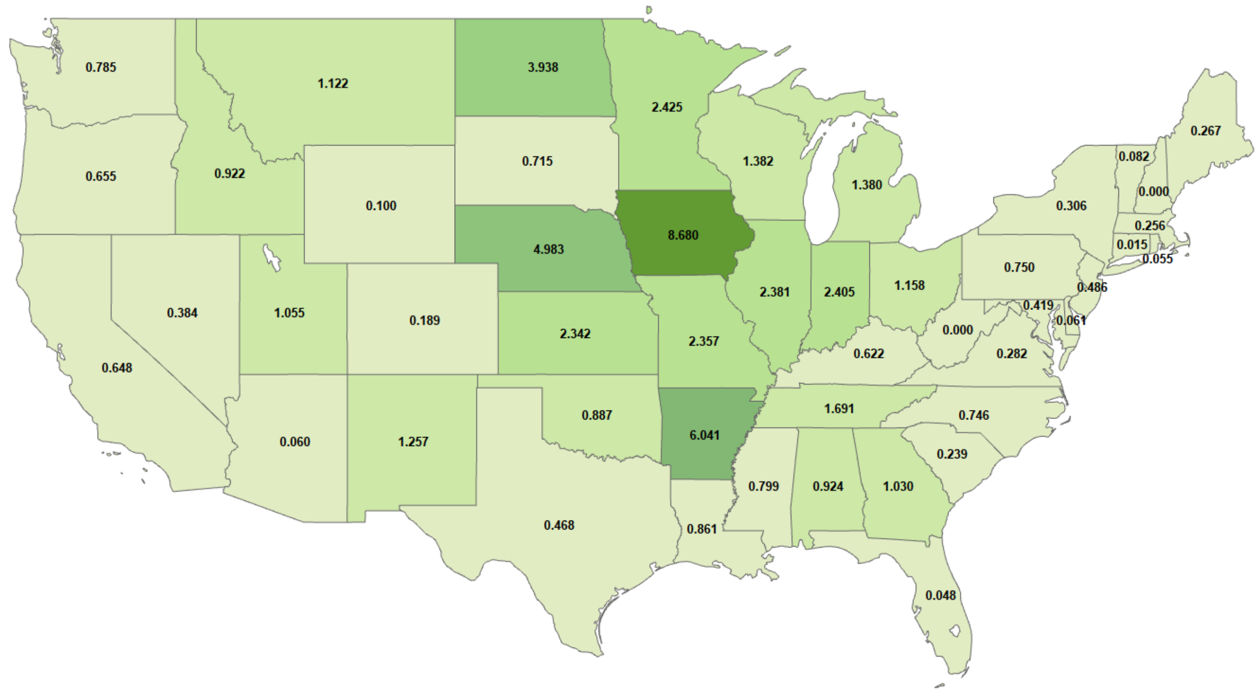
If alternative materials are to be introduced into the product design process, it must be done early in the product development cycle, because introducing a new material later in the process can create a significant hurdle that could have a negative impact on the production value stream. The other point is to ensure that the right metrics are driving the right types of design and engineering behaviors. Deere uses a set of key sustainability metrics called EcoMetrics, which consider water waste, product waste, customers' use, greenhouse gases, and the fuel efficiency of the vehicles. All of these metrics must be considered simultaneously when product design decisions are made.

Deere is continuing to explore other biobased materials for use in its products. This includes soy urethane foams for seating and arm rests, soy based foam seats, natural fiber reinforcements and fillers (such as hemp-based materials), thermoplastics, nylons using castor oil, biomass-filled polypropylene for injection molding thermoplastics, and biorubber. The cost and commercial properties of these technologies will continue to be monitored over time so that informed decisions can be made concerning their commercial use.

Source: USDA Flickr, photo by Bob Nichols. Soybeans at the USDA Agricultural Research Service Center in Beltsville, MD. https://www.flickr.com/photos/usdagov/15710096275/in/album-72157649122400522, accessed May 2015.

B. Biorefining

Figure 8: Location Quotients for Biorefining Grain and Oilseed Milling in 2013



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.[17] *Many of these refineries are producing co-products that support the U.S. biobased products industry.*

Major U.S.-Based Firms[18]

Cargill (Minnesota)
Archer Daniels Midland (Illinois)
Poet LLC (South Dakota)
Valero (Texas)
Green Plains Renewable Energy (Nebraska)
Flint Hills Resources (Kansas)

Economic Statistics

Total value added to U.S. economy in 2013: $1.18 billion

Type SAM Multiplier: 7.60 in 2013

Employment Statistics

Total number of Americans employed due to industry activities in 2013: 11,300

SAM Employment Multiplier: 19.7 in 2013

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[17] Renewable Fuels Association, Biorefinery Locations, Renewable Fuels Association website, http://www.ethanolrfa.org/bio-refinery-locations/, accessed April 2015.

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

Table 3. Distribution of Direct Value Added and Employment by Sub-Sector

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
70	311221	Wet corn milling	260	$89,370,000
74	311313	Beet sugar manufacturing	120	$21,294,000
75	311311, 311312	Sugarcane mills and refining	100	$26,040,000
71	311222, 311223	Soybean and other oilseed processing	60	$12,616,000
72	311225	Fats and oils refining and blending	40	$6,007,000
		Totals	570	$155,327,000

According to the Department of Energy's National Renewable Energy Laboratory, a biorefinery integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass.[19] It is very similar to a petroleum refinery, which produces multiple fuels and co-products ranging from solvents to asphalt from petroleum.

By producing multiple products, a biorefinery can take advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock. For example, a biorefinery might produce one or several low-volume, high-value chemical products and a low-value, high-volume liquid transportation fuel, while simultaneously generating process heat for its own use and perhaps enough electricity to meet its own needs and sell some to the grid. The high-value products enhance profitability, the high-volume fuel helps meet national energy needs, and the power production reduces costs and reduces emissions of greenhouse gases.[20]

Conversion Processes
Depending on the nature of the feedstock and the desired output, biorefineries use a variety of conversion technologies.

First-Generation Processes
First-generation liquid biofuels include ethanol from sugar/starch and biodiesel from oil/fats. Currently, most of these two products are made using conventional technology.

First-generation chemicals and materials from sugar/starch include polymers, such as polylactic acid (PLA), and chemical building blocks, such as succinic acid and 1,3 propanediol. Chemicals from vegetable oils include fatty acids and esters. Ethanol is a building block for the production of polymers, such as polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET).

[19] National Renewable Energy Laboratory (NREL), What is a Biorefinery?, NREL website, http://www.nrel.gov/biomass/biorefinery.html, accessed April 2015.

[20] National Renewable Energy Laboratory (NREL), What is a Biorefinery?, NREL website, http://www.nrel.gov/biomass/biorefinery.html, accessed April 2015.

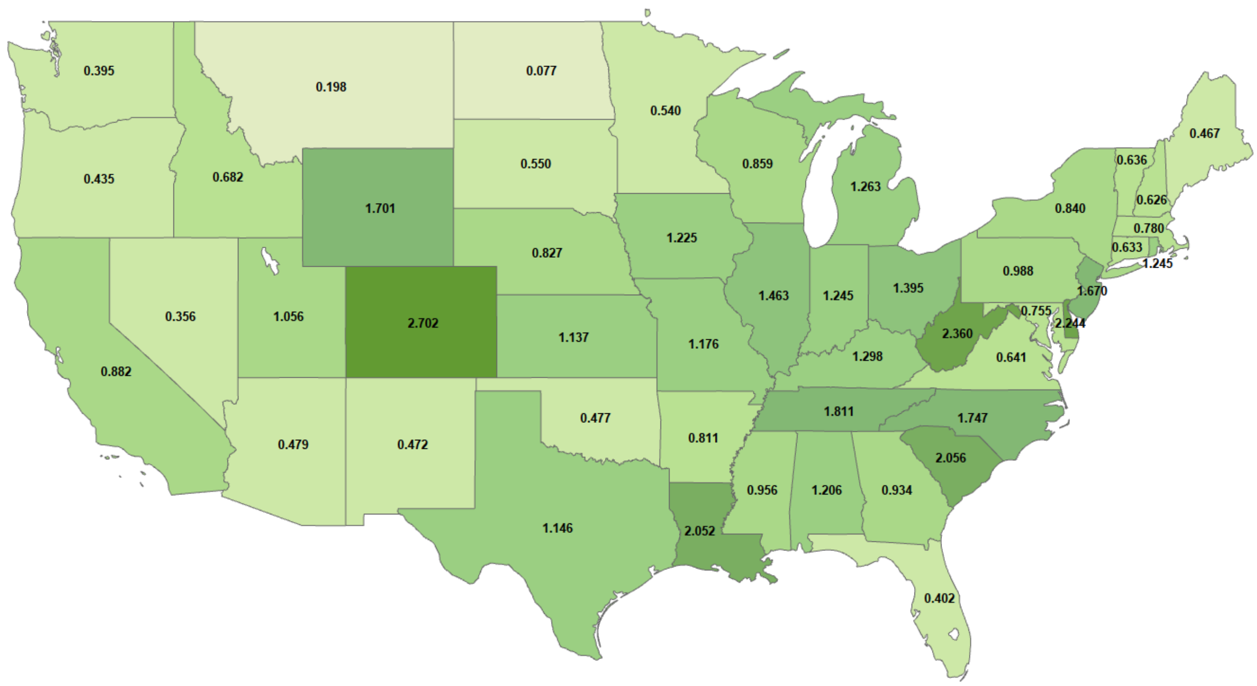
Second-Generation Processes
Second-generation biofuels include cellulosic ethanol, BtL (biomass to liquid) diesel, and other BtL fuels. These biofuels are still generally in the demonstration stage, even for the most advanced products. Internationally, there is increasing interest in the use of cellulosic biomass for the production of second-generation chemicals and materials.

Biorefining Non-Fuel Co-products
Co-products will have an increasingly important role in the economic growth and profitability of biobased products. In part, this will likely follow the value chain development of the petroleum sector, which was able to obtain co-product benefits from over 6,000 petroleum-derived co-products, such as alkenes (olefins), lubricants, wax, sulfuric acid, bulk tar, asphalt, petroleum coke, paraffin wax, and aromatic petrochemicals that are used for production of hydrocarbon fuels and hydrocarbon chemicals.[21]

[21] Sticklen MB (2013) Co-Production of High-Value Recombinant Biobased Matter in Bioenergy Crops for Expediting the Cellulosic Biofuels Agenda. Adv Crop Sci Tech 1: http://dx.doi.org/10.4172/2329-8863.1000e101.

C. Biobased Chemicals

Figure 9: Location Quotients for the Biobased Chemical Sector Including Enzymes (Covered in the Following Section) in 2013



Chemical demand is expected to strengthen in 2015, with growth expected to exceed 3.0% in both the United States and the overall global market for the first time in four years, and reach 3.6% in 2015, and 3.9% in 2016.[22]

Major U.S.-Based Firms[23]

DuPont (Delaware)
Sherwin-Williams Co. (Ohio)
Myriant (Massachusetts)
NatureWorks (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 2013 $17.4 billion

Type SAM Economic Multiplier in 2013: 3.47

Employment Statistics

Total number of Americans employed due to industry activities in 2013: 133,000

Type SAM Employment Multiplier in 2013: 5.80

[22] IHS Chemical Week, Leading Indicators, IHS Chemical Week website, http://www.chemweek.com/economics/leading_indicators/, accessed April 2015.
[23] Forbes, The World's Biggest Public Companies, Forbes website, http://www.forbes.com/global2000/list/, accessed April 2015.

Table 4. Distribution of Direct Value Added and Employment by Sub-Sector

IMPLAN Code	NAICS Code	Description	Employment	Value Added
196	32621	Tire manufacturing	2,130	$293,000,000
182	325620	Toilet preparation manufacturing	2,110	$752,000,000
198	32629	Other rubber product manufacturing	2,170	$233,000,000
166	325211	Plastics material and resin manufacturing	2,340	$622,000,000
165	32519	Other basic organic chemical manufacturing	2,050	$503,000,000
177	325510	Paint and coating manufacturing	1,590	$334,000,000
187	325998	Other miscellaneous chemical product manufacturing	1,470	$292,000,000
193	326150	Urethane and other foam product (except polystyrene) manufacturing	1,290	$133,000,000
192	326140	Polystyrene foam product manufacturing	1,120	$134,000,000
168	32522	Artificial and synthetic fibers and filaments manufacturing	1,060	$177,000,000
179	325611	Soap and other detergent manufacturing	1,000	$532,000,000
197	326220	Rubber and plastics hoses and belting manufacturing	950	$106,000,000
180	325612	Polish and other sanitation good manufacturing	950	$317,000,000
178	325520	Adhesive manufacturing	820	$155,000,000
185	325991	Custom compounding of purchased resins	680	$111,000,000
186	325992	Photographic film and chemical manufacturing	650	$118,000,000
183	325910	Printing ink manufacturing	370	$58,000,000
181	325613	Surface active agent manufacturing	200	$162,000,000
		Totals	22,950	$5,032,000,000

We estimate that bioplastic production in the United States was approximately 0.3% of total annual production of plastic, and we estimate that the entire chemical sector was 4% biobased.[24] Estimates of the future penetration of the market by 2025 vary from as little as 6 to 10% for commodity chemicals to as much as 45-50% for specialty and fine chemicals.[25,26]

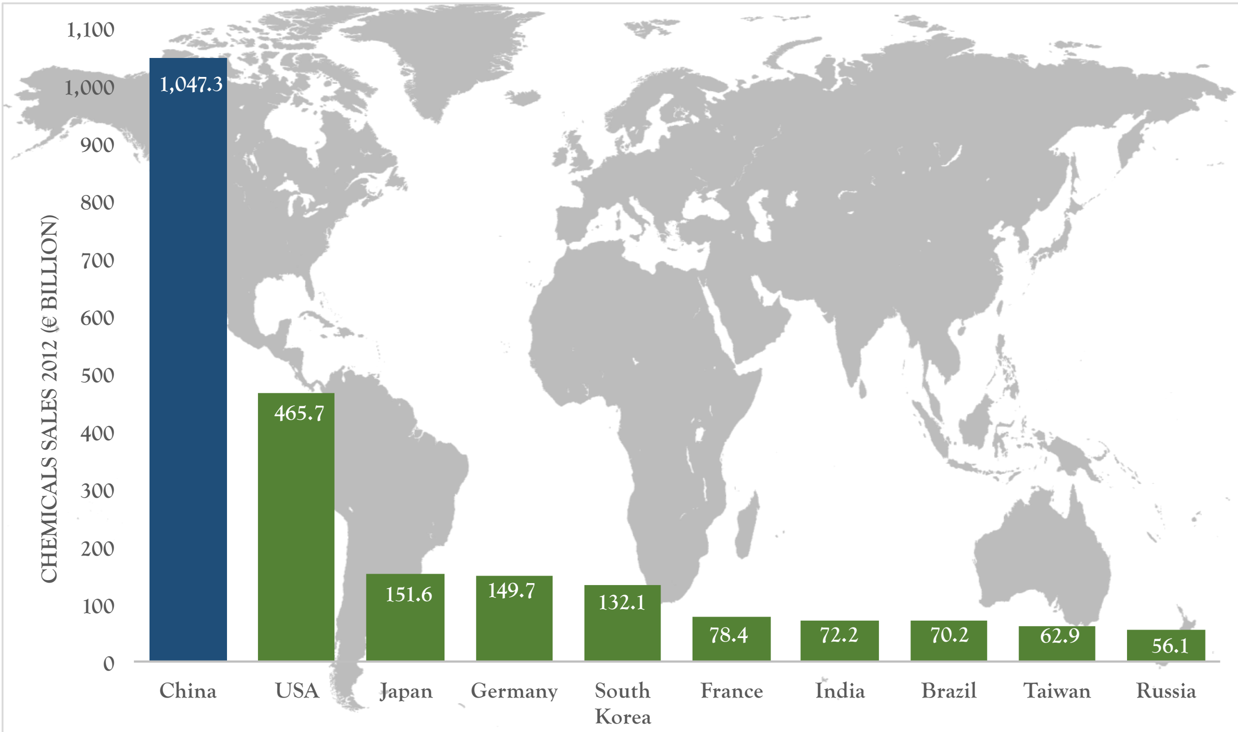
[24] BCC Research (2014) "Biorefinery Applications: Global Markets."

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

[26] 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.

Figure 10: Chemical Sales by Country in Euros (€) -Top 10

Note: Excludes Pharmaceuticals; $1 USD = €0.809 in 2012.



Source: Cefic, Facts and Figures 2014, Cefic website, http://www.cefic.org/Facts-and-Figures/, accessed April 2015.

Although basic chemicals made up around 60% of global chemical sales in 2010, only 4% of these (16.1 billion Euros) were produced using biotechnological processes. However, 2015 figures suggest this figure could be as high as 12% for chemicals.[27] A 2008 USDA study suggested that the typical percent of biobased products in chemical categories is 2% of total market share, and projected to grow to 22% by 2025.[28] According to the Biotechnology Industry Organization (BIO), the number of jobs in the biobased chemical sector is projected to rise from 40,000 in 2011 to 237,000 in 2025. Additionally, BIO projects that biobased chemical sales will increase from approximately 4% of total chemical sales to 20% during the same timeframe.[29]

Figure 10 shows that the U.S. is a significant leader in the global chemical sector, ranking second to China. According to the American Chemistry Council, the production of specialty chemicals will be driven by strong demand from end-use markets; consumer products demand will moderate in 2015 and 2016.[30] Demand for agricultural chemicals

[27] Festel G, Detsel C, and Mass R (2012) Industrial biotechnology — Markets and industry structure. J Commer Biotechnol 18(1): 11-21.
[28] USDA "U.S. Biobased Products Market Potential and Projections Through 2025," USDA website, http://www.usda.gov/oce/reports/energy/BiobasedReport2008.pdf, accessed April 2015.

[29] BIO, BIO's Pacific Rim Summit Will Highlight Growth in California's Advanced Biofuels and Biorenewables Sector, BIO website, https://www.bio.org/media/press-release/bio%E2%80%99s-2014-pacific-rim-summit-will-highlight-growth-california%E2%80%99s-advanced-biofue, accessed April 2015.
[30] American Chemistry Council, "Year-End 2013 Chemical Industry Situation and Outlook: American Chemistry is Back in the Game." http://www.americanchemistry.com/Jobs/EconomicStatistics/Year-End-2013-Situation-and-Outlook.pdf, accessed April 2015.

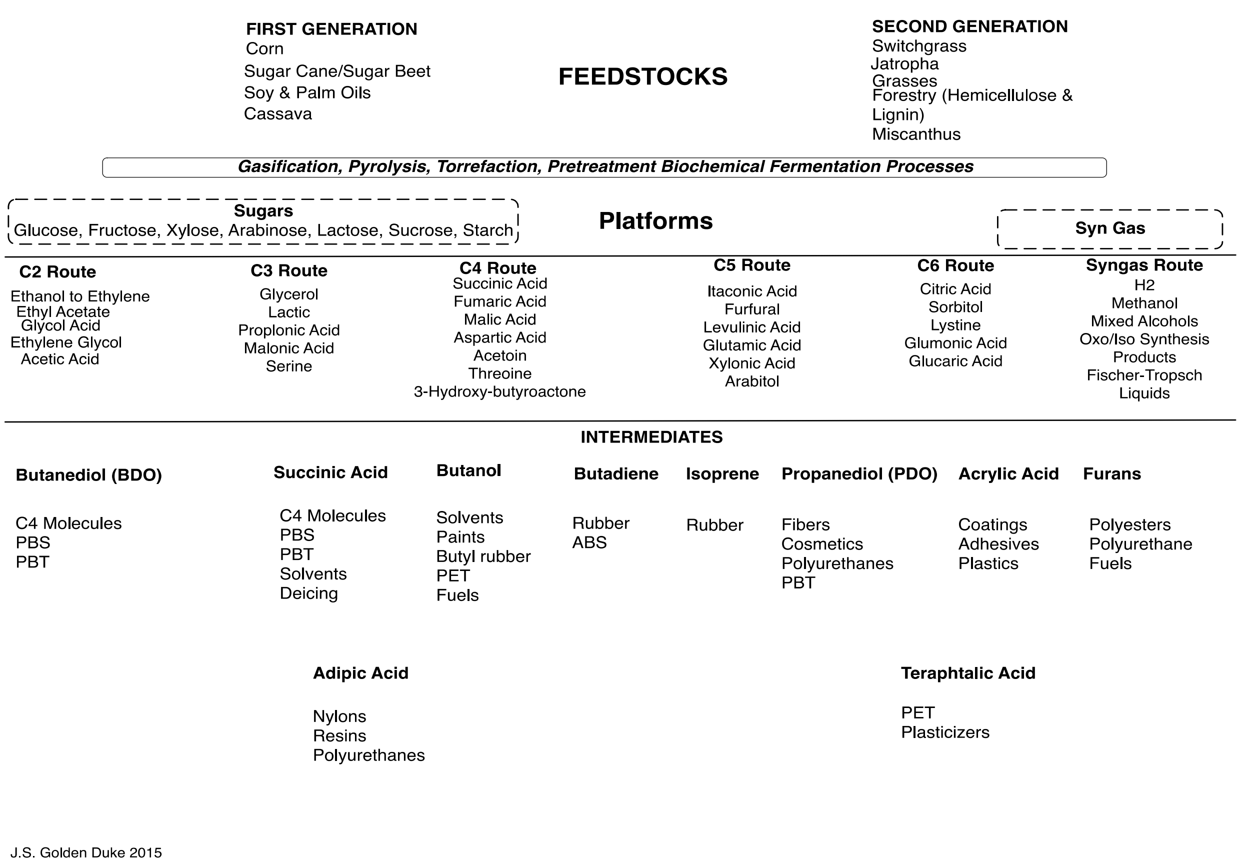
(and U.S. sales) will be strong again. During the second half of the decade, U.S. chemical industry growth is expected to expand at more than four percent per year on average, exceeding the expansion of the overall U.S. economy. Consider that 96% of all goods manufactured in the U.S. incorporate a chemical product, accounting for almost $3.6 trillion of the U.S. gross domestic product (GDP).[31] This provides unique opportunities to create a wide range of biobased chemicals that could improve the environmental performance of those products while also stimulating the U.S. economy. Replacing 20% of the current plastics produced in the U.S. with bioplastics could create about 104,000 jobs in the U.S.[32]

Figure 11 illustrates the flow of biobased chemicals from feedstocks to intermediates to products. While much of the focus on the bioeconomy has been on biobased fuels and energy sources, our focus was on manufactured goods. However, one cannot simply exclude the energy and fuel sectors, because both infrastructure and co-products are parts of an integrated biobased products system. Currently, most biopolymers are made in large biorefineries. For example, PLA is produced at a plant near the Cargill wet mill corn refinery in Blair, Nebraska.

[31] Milken Institute Financial Innovations® Lab. "Unleashing the Power of the Bioeconomy," Milken Institute website, http://assets1b.milkeninstitute.org/assets/Publication/InnovationLab/PDF/BioEconFIL.pdf, accessed April 2015.

[32] Heintz J and Pollin R (2011) The Economic Benefits of a Green Chemical Industry in the U.S.: Renewing Manufacturing Jobs While Protecting Health and the Environment. Political Economy Research Institute, Amherst, MA.

Figure 11: Process Flow of Biobased Chemicals



This plant produces the dextrose that is used as a feedstock, and it also produces sweeteners, corn oil, and other corn-based products. While biopolymers can be made from a wide range of biobased materials, most of the biopolymers that are currently marketed are made from starch. Currently, corn is the primary feedstock, but potatoes and other starch crops also are used in lesser amounts. As an example of the raw material to product ratio, roughly 2.5 lb. of corn (15% moisture) are required to make 1 lb. of PLA.

Bioplastics

In the past, plastics have been derived primarily from petrochemicals, but, in recent years, significant quantities of these plastics have been replaced by biobased plastics. There are two general types of plastics: thermosets and thermoplastics. Thermosets melt and take the shape of the mold, and they maintain that shape after they solidify because the chemical reaction that occurs is irreversible. Conversely, thermoplastics do not undergo changes in their chemical composition when they are heated, so they can be molded again and again. Both types of plastics can be produced from renewable resources. The family of bioplastics is generally considered to be divided into three main groups:

1. Biobased or partly biobased non-biodegradable plastics, such as biobased PE, PP, and PET (which can be used as direct replacement for petroleum-based plastics) and biobased technical performance polymers, such as PTT and TPC-ET.
2. Plastics that are both biobased and biodegradable, such as PLA, PHA, and PBS.
3. Plastics that are based on fossil resources and are biodegradable, such as PBAT.

Bioplastics are plastics made in whole or in part of renewable resources. They include:

- Starch plastics
- Cellulosic polymers
- PLA
- Polytrimethylene terephthalate (PTT) from biobased 1,3-propanediol (PDO)
- Polyamides (nylon)
- Polyhydroxyalkanoates (PHAs)
- Polyethylene (PE)
- Polyvinyl chloride (PVC) from biobased PE
- Other biobased thermoplastics (polybutylene terephthalate (PBT))
- Polybutylene succinate (PBS)
- Polyethylene terephthalate (PET)
- Polyethylene-co-isosorbide terephthalate polymer (PEIT)
- Polyesters based on PDO Polyurethane (PUR) from biobased polyols
- Biobased thermosets.

Globally, bioplastics make up nearly 300,000 metric tons of the plastics market, which amounts to less than one percent of the 181 million metric tons of synthetic plastics produced worldwide each year. While the market for bioplastics is increasing by 20 to 30% per year, this growth may not be sufficient to meet the projected demand. For a few years, natural food purveyors, such as Newman's Own Organics and Wild Oats, have been using some PLA products, but the material got its biggest boost when Walmart, the world's largest retailer, announced that it would sell some produce in PLA containers.[33] Table 5 shows the biobased content of many biopolymers.

Polylactic acid (PLA) is one of the many biobased polymers. An important feature of starch produced by green plants is its potential enzymatic hydrolysis into glucose with subsequent fermentation into lactic acid.

[33] Madhavan Nampootheri K, Nair NR, and John RP (2010) An overview of the recent developments in polylactide (PLA) research. Bioresource Technol, 101(22): 8493-8501.

Table 5. Average Biobased Content of Biobased Polymers

Biobased Polymers		Average Biobased Content of the Polymers, %
Cellulose Acetate	CA	50
Polyamide	PA	Rising to 60
Polybutylene Adipate Terephthalate	PBAT	Rising to 50
Polybutylene Succinate	PBS	Rising to 80
Polyethylene	PE	100
Polyethylene Terephthalate	PET	Up to 35
Polyhydroxy Alkanoates	PHAs	100
Polylactic Acid	PLA	100
Polypropylene	PP	100
Polyvinyl Chloride	PVC	43
Polyurethane	PUR	30
Starch Blends (in plastic compounds)		40

Source: Dammer L, Carus M, Raschka A, and Scholz L (2013) Market Developments of and Opportunities for biobased products and chemicals, nova- Institute for Ecology and Innovation, Germany.

PLA can be obtained from this fermentation product via direct condensation or via its cyclic lactide form. PLA has been fabricated into fibers, films, and surgical implants and sutures. Currently, most PLA is produced by NatureWorks (Cargill-PTT Global Chemical), which produces 136,000 metric tons per year in its plant in Nebraska.[34] Biobased PLA has several properties that make it attractive for many uses, e.g., it is renewable, biodegradable, recyclable, compostable, biocompatible, and processable; in addition, it saves energy. However, PLA has poor toughness, degrades slowly, and is hydrophobic; also, it lacks reactive side-chain groups.[35] The main concern with PLA is its price. On an industrial scale, producers are seeking a target manufacturing cost of lactic acid monomer of less than $0.80/kilogram (kg) because the selling price of PLA should decrease from its present price of $2.20/kg.[36] According to the cost analysis, the base manufacturing cost of lactic acid was estimated to be $0.55/kg. There are several issues that must be addressed for the biotechnological production of lactic acid, such as the development of high-performance lactic acid-producing microorganisms and reducing the costs of the raw materials and fermentation processes.[37]

Polyhydroxyalkanoates (PHAs) are linear polyesters produced in nature by bacterial fermentation of sugars and lipids. They are produced by the bacteria to store carbon and

[34] Mooney R (2009) The second green revolution? Production of plant-based biodegradable Plastics. Biochem J 418(2): 219 – 232.

[35] Rasal RM, Janorkar AV, and Hirt DE (2010) Poly(lactic acid) modifications. Prog Polym Sci 35(3): 338 – 356.

[36] This cost is for a 108 million lb. per yr. plant in the midwestern U.S. with carbohydrate raw material priced at $0.06/lb. The cost can vary based on the raw material, technology, plant size, and percentage change in capital investment. The technological and economic potential of polylactic acid and lactic acid derivatives is discussed in Datta et al. (1995). Datta R, Tsai SP, Bonsignore P, Moon SH, and Frank JR (1995) Technological and economic potential of poly-lactic acid and lactic acid derivatives. FEMS Microbiol Rev 16: 221-231.

[37] Madhavan Nampootheri K, Nair NR, and John RP (2010) An overview of the recent developments in polylactide (PLA) research. Bioresource Technol 101(22): 8493-8501.

energy. PHAs can be used for the manufacture of films, coated paper, and compost bags; they also can be molded into bottles and razors.[38] Co-polymers of PHAs are more useful for industry, since they exhibit lower crystallinity and easy processability; also, the final products are very flexible.

Plant Oils are primarily triacylglycerides that can be used directly for the synthesis of a variety of polymers. For instance, they have been used in the synthesis of coatings, often avoiding additional costs and avoiding the time required to modify the starting materials.[39] A wide range of polymerization methods has been investigated, including condensation, radical, cationic, and metathesis procedures. The scope, limitations, and possibility of utilizing these methods for producing polymers from triacylglycerides were reviewed by Güner and co-workers.[40] The primary sources of oils are soybeans and castor oil plants. Because castor oil contains ricinoleic acid, a monounsaturated, 18-carbon fatty acid, it is more polar than other fats, which allows chemical derivatization not possible with other seed oils. Castor oil and its derivatives are used in the manufacturing of soaps, lubricants, hydraulic fluids, brake fluids, paints, dyes, coatings, inks, cold resistant plastics, waxes, polishes, nylon, pharmaceuticals, and perfumes.

Fatty Acids (FA) and fatty acid methyl esters (FAME) can be used directly or after functionalization as monomers for the synthesis of a variety of polymeric materials. The most important functionalization possibilities of the double bonds and the ester groups have been reviewed extensively in the literature.[41,42,43] It is encouraging that there are carbohydrate-based and plant oil-based polymers that could be substituted, at least partially, for the mineral oil-based materials that are currently in the market. Although some renewable polymeric materials already have been commercialized, others are still not economically feasible for large-scale production.[44]

Biolubricants can be either vegetable-based oils, such as rapeseed oils, or synthetic esters manufactured from modified oils and mineral oil-based products. Examples of end uses of the product include aviation, automotive, and marine applications, as well as power tool lubricants and drilling fluids.

Biosolvents are soy methyl ester (soy oil esterified with methanol), lactate esters (fermentation-derived lactic acid reacted with methanol or ethanol), and D-limonene, which is extracted from citrus rinds. One of the primary benefits of biosolvents is that they do not emit volatile organic compounds (VOCs) that are of concern from the perspectives of workers' safety and adverse environmental impacts. Biosolvents primarily are used as degreasing agents for metals and textiles, and they also are used to strip household paint, to remove glue, and as diluents for paints and

[38] Mooney R (2009) The second green revolution? Production of plant-based biodegradable Plastics. Biochem J 418 (2): 219 – 232.
[39] Derksen JTP, Cuperus FP, and Kolster P (1995) Paints and coatings from renewable resources. Ind Crops Prod 3(4): 225-236.
[40] Güner FS, Yağcı Y, and Erciyes AT (2006) Polymers from triglyceride oils. Prog Polym Sci 31, 633–670.
[41] Biermann U, Furmeier S, and Metzger JO (2001) New Chemistry of Oils and Fats. Oleochemical Manufacture and Applications (Eds. FD Gunstone, RJ Hamilton) Sheffield Academic Press and CRC Press. ISBN 1-84127-219-1, pp. 266-299.
[42] Biermann U, Butte W, Eren T, Haase D, and Metzger JO (2007) Reio-and Stereoselective Diels-Alder Additions of Maleic Anhydride to Conjugated Triene Fatty Acid Methyl Esters. Eur J Org Chem (23): 3859-3862.
[43] Biermann U and Metzger JO (2004) Catalytic C,C-Bond Forming Additions to Unsaturated Fatty Compounds. Top Catal 38: 3675-3677.
[44] Türünç O and Meier M (2012) Biopolymers. Chapter in Food and Industrial Biobased products and Bioprocessing, First Edition (Ed. NT Dunford) John Wiley & Sons, Inc.

pesticides. They also are used as extraction solvents in perfumes and pharmaceuticals.

Biosurfactants are generally derived from plant oils, such as palm oil and coconut oil, and from plant carbohydrates, such as sorbitol, sucrose, and glucose. These surfactants are used to make household detergents, personal care products, food processing products, textiles, coatings, pulp and paper products, agricultural chemicals, and industrial cleaners.

Other Biosynthetics to replace ingredients based on petrochemicals, such as isoprene, which is used in manufacturing synthetic rubber, with renewable biomass, i.e., BioIsoprene™ are being researched and tested. Examples of biosynthetic end products include car tires, motor oils, marine lubricants, food grade lubricants, dielectric fluids, refrigeration coolants, and personal care products, such as skin-care products, hair-care products, and cosmetics.

Commodity plastics, such as PE, PP, and PVC, also can be made from renewable resources, such as bioethanol. Bio-PE is already produced on a large scale (200,000 metric tons per year by Braskem, Brazil; additional projects are planned by Dow Chemical Company). Bio-PP and Bio-PVC are soon to follow. The partially-biobased polyester PET is used both for technical applications and for packaging (mainly for beverage bottles, e.g., by Coca-Cola). Because the value-added chain only requires adaptation at the outset, and the properties of the products are identical to those of the fossil-based products, they also are referred to as 'drop-in' bioplastics.

Biobased, non-biodegradable technical/performance polymers contain many specific polymers, such as biobased polyamides (PA), polyesters (e.g., PTT and PBT), polyurethanes (PUR), and polyepoxides. They are mainly used in seat covers, carpets, and other automotive applications, such as foams for seating, casings, cables, hoses, and covers. Usually, their life cycles are several years. Therefore, they are referred to as 'durables,' and biodegradability is not a sought-after property.

Biobased, biodegradable plastics include starch blends made of modified starch and other biodegradable polymers, as well as polyesters, such as polylactic acid (PLA) and polyhydroxyalkanoate (PHA). Unlike cellulosic materials, biobased, biodegradable plastics have been available on an industrial scale only for the past few years. So far, they have been used primarily for short-lived products, such as packaging, but this large, innovative area in the plastics industry continues to grow as new, biobased monomers are introduced, such as succinic acid, butanediol, propane diol, and fatty acid derivatives. Several materials in this group, such as PLA, currently are being used for end-of-life solutions, such as recycling, rather than biodegradation.

Inks and Dyes are an important part of this sector as well. Currently, over 90% of U.S. newspapers and 25% of commercial printers use soy-based ink toner for printers and copiers, ink for ballpoint pens, and lithographic inks that are UV curable. The market share for vegetable oil-based inks increased from five percent in 1989 to approximately 25% in 2002.[45,46]

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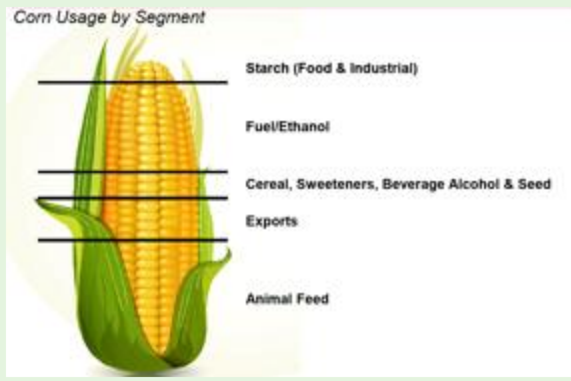
[45] Informa Economics, Inc. (2006) The Emerging Biobased Economy: A multi-client study assessing the opportunities and potential of the emerging biobased economy. Developed by Informa Economics, Inc. in Participation with MBI International and The Windmill Group.

[46] USDA "U.S. Biobased Products Market Potential and Projections Through 2025," USDA website, http://www.usda.gov/oce/reports/energy/BiobasedReport2008.pdf, accessed April 2015.

C1. Case Study: Penford – 120 Years in the Making

Although biobased products are relative newcomers in some industrial sectors, one company, Penford, has been in the biobased product business for over 120 years. Penford produces a variety of products used in a number of applications, including adhesives, paper, packaging, construction products, and oil and gas drilling that are all produced from starch. Greg Keenan, Vice President of Business Development, admits that “our industry needs to do a better job of promoting the significant amount of biopolymers and biobased products that are readily available today.” Starch is a carbohydrate polymer extracted from a variety of plants, with the majority coming from corn, with lesser amounts coming from potatoes, rice, tapioca, and wheat. Starch also is the second most abundant natural polymer after cellulose, and it is easily extracted and readily available from natural agricultural sources. Usually starch is a mixture of two polymers, i.e., amylose and amylopectin.

In addition to being available, renewable, and biodegradable, starch is also highly versatile and is an ideal polymer for environmentally-driven applications. It can be used in its native form, or it can be modified physically and/or chemically for use in a variety of food and industrial applications. In the United States, starch is recovered mostly from corn in biorefineries that produce a variety of products, including food ingredients, animal feed, biofuels, and industrial biobased products. Corn is processed in a wet mill where the starch is separated and then converted and modified through physical, chemical, and enzymatic processes that produce a variety of higher value molecules and functionalities. The major producers of starch are Ingredion, Tate & Lyle, Archer Daniels Midland, Cargill, GPC, Penford, and Roquette.



In 2013, U.S. corn biorefineries processed 1.5 billion bushels of corn (~ 10% of the U.S. corn crop), yielding about 47 billion pounds of starch. The largest use of starch from corn is in sweeteners (> 50%), followed by ethanol (30%). Approximately eight billion pounds (17%) of modified and unmodified starch are sold annually, with 70% of the total being modified starch and 30% being unmodified starch. Penford’s predominant activity is the production of modified and unmodified starch. Starch also can be fermented for use in other products, such as algae-based products (Solazyme) or chemical products (Amyris). Of the eight billion pounds, about two-thirds is used in industrial (non-food) applications, and one-third is used in the paper industry for various applications, such as wet end sizing, surface sizing, coatings, and adhesives. More than 70% of natural adhesives are starch-based.

Although Penford's origins were based on producing starch for food products, the company has focused on innovation for a number of years to explore variations of starch that can be used for new applications and for replacing petroleum-based products. Using starch as feedstocks, scientists have been able to develop starch-derived polymers, modify them, and react them with other polymers to make new products. With a very high mass conversion yield, Penford is able to produce interesting products that are economically competitive with petroleum, even at today's comparatively low oil prices. There are several examples of these applications. One example is synthetic latex, which is obtained from crude oil, so its cost is largely dependent on crude oil prices. Penford developed a novel biopolymer that improves the performance, economics, and sustainability of latex coatings and adhesives, and the petroleum content of the biopolymer was reduced by 50% or more in many applications. The company has developed several natural binders ("Pen-Cote®") that complement synthetic latex. When used in packaging coatings that contain synthetic latex, Pen-Cote binders improve performance, reduce cost, and add biobased content to the coating. This has been a growing market, and now Pen-Cote is used in 43% of coated recycle board and in 55% of carton carriers.

Another product, PenCare DP, represents a new family of naturally-based deposition ingredients built on a novel, patent-pending cationic biopolymer. Major applications are in consumer care products, including shampoos, conditioners, and body washes ("rinse-off" products), as well as lotions, styling products, and conditioners ("leave-on" products). In comparison to industry standards, PenCareDP has been very competitive.

Another Penford product, a specialty adhesive was developed specifically for U.S. Playing Cards, the leader in the production and distribution of premier playing cards including brands such as BEE, BICYCLE, KEM, AVIATOR, and HOYLE. Penford developed a proprietary adhesive formula, using a modified starch polymer, which improved the performance of the laminating process. For this product, significant collaboration between the technical teams was critically important to achieve the desired consistency and performance of the product. The product is used in a large number of card decks; laid end to end, the number of cards produced per year would go around the earth 11 times.

D. Enzymes

Source: Novozymes. Standardization tanks at Novozymes, Franklinton, North Carolina.
http://www.novozymes.com/en/news/image/Pictures/Novozymes%20012.jpg

Enzymes are used in a wide range of industrial sectors, including the production of biofuels, washing detergents, foods and animal feed, and biobased chemicals. In 2010, the global market for industrial enzymes was valued at $3.6 billion. Food and beverage enzymes comprise the largest segment of the industrial enzymes industry, with revenues of nearly $1.2 billion in 2010; the market for enzymes for technical applications was $1.1 billion in 2010.[47]

Major U.S.-Based Firms

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

[47] EuropaBio, EuropaBio website, http://www.europabio.org/, accessed April 2015.

Global Firms with a Presence in the U.S.

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

Economic Statistics

Total value added to the U.S. economy in 2013: $4.4 billion

Type SAM Economic Multiplier in 2013: 5.09

Employment Statistics

Total number of Americans employed due to industry activities in 2013: 32,000

Type SAM Employment Multiplier in 2013: 10.6

Table 6. Distribution of Direct Value Added and Employment by Sub-Sector

IMPLAN Code	NAICS Code	Description	Employment	Value Added
165	32519	Other basic organic chemical manufacturing	2,010	$494,000,000
176	325414	Biological product (except diagnostic) manufacturing	990	$379,000,000
		Totals	3,000	$873,000,000

Enzymes are biological catalysts in the form of proteins that catalyze chemical reactions in the cells of living organisms. In general, these metabolic requirements include:

1. Chemical reactions must take place under the conditions of the habitat of the organism
2. Specific action by each enzyme
3. Very high reaction rates.

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. Table 7 summarizes classes of enzymes and their uses.

The total market for enzymes in the United States is approximately $4.4 billion. They are used in the consumer products market (36%), food and beverages (27%), bioenergy (16%), agriculture and feed (14%), and pharmaceuticals (7%). Based on prior research, we estimate that enzymes comprise 4% of the organic chemical production market.[48]

[48] Interview with Amy Davis, Government Relations, Novozymes, 2015.

Table 7. Enzyme Classification and Reaction Profiles

Enzyme Classification	Reaction Profile
EC 1. Oxidoreductases	These enzymes catalyze redox reactions, i.e., reactions that involve the transfer of electrons from one molecule to another. In biological systems, hydrogen atoms often are removed from a substrate. Typical enzymes that catalyze such reactions are called dehydrogenases. For example, alcohol dehydrogenase catalyzes reactions of the type $R\text{-}CH_2OH + A \rightarrow R\text{-}CHO + AH_2$, where A is a hydrogen acceptor molecule. Other examples of oxidoreductases are oxidases and laccases, both of which catalyze the oxidation of various substrates byO_2, and peroxidases that catalyze oxidation by hydrogen peroxide. Catalases are a special type of enzyme that catalyze the disproportionation reaction, $2\ H_2O_2 \rightarrow O_2 + 2\ H_2O$, whereby hydrogen peroxide is both oxidized and reduced at the same time.
EC 2. Transferases	Enzymes in this class catalyze the transfer of groups of atoms from one molecule to another or from one position in a molecule to other positions in the same molecule. Common types are acyltransferases and glycosyltransferases. Cyclodextrin glycosyltransferase (CGTase) is one such enzyme, and it moves glucose residues within polysaccharide chains in a reaction that forms cyclic glucose oligomers (cyclodextrins).
EC 3. Hydrolases	Hydrolases catalyze hydrolysis, the cleavage of substrates by water. The reactions include the cleavage of peptide bonds in proteins by proteases, glycosidic bonds in carbohydrates by a variety of carbohydrases, and ester bonds in lipids by lipases. In general, larger molecules are broken down to smaller fragments by hydrolases.
EC 4. Lyases	Lyases catalyze the addition of groups to double bonds or the formation of double bonds through the removal of groups. Thus, bonds are cleaved by a mechanism different from hydrolysis. Pectate lyases, for example, split the glycosidic linkages in pectin in an elimination reaction, leaving a glucuronic acid residue with a double bond.
EC 5. Isomerases	Isomerases catalyze rearrangements of atoms within the same molecule; e.g., glucose isomerase will convert glucose to fructose.
EC 6. Ligases	Ligases join molecules with covalent bonds in biosynthetic reactions. Such reactions require the input of energy by the concurrent hydrolysis of a diphosphate bond in adenosine triphosphate (ATP), a fact that makes this kind of enzyme difficult to use commercially.

Source: Novozymes, “Enzymes at work,” Novozymes website, http://www.novozymes.com/en/about-us/brochures/Documents/Enzymes_at_work.pdf, accessed April 2015.

D1. Case Study: Enzyme production at Novozymes – A Growing Market in Products Used Every Day

Novozymes is a major producer of biobased enzymes, with headquarters in Copenhagen and major manufacturing sites all over the world, including Franklin County, not far from NC State University. Its products, enzymes, are used in multiple industries, including beer, leather, feedstocks, detergents, consumer products, and a multitude of products that most people know by brand. The core strength of the company is to replace chemicals with biotechnology, improve efficiency, and increase the use of biofuels. The company's goals are to help customers derive new solutions, and it has worked with several large companies, including Procter & Gamble, Unilever, and Colgate. Sustainability is often viewed in many organizations as a concept or an aspiration. But at Novozymes, it is a fundamental part of the organization's vision, and it has several implications. First, sustainability is viewed as a daily practice, and it reflects the company's values, voices, standards, and functional strategies. Second, it is communicated externally, and systems are used to track and measure actual activities against sustainability objectives. Third, appropriate incentives must be part of a sustainability program, and these include bonuses, salary, and stock options.

Novozymes has taken these steps to integrate sustainability into all parts of the organization. The company established a Sustainability Development Board (SDB), consisting of sales, marketing, supply chain, research and development, and others to ensure stakeholder engagement. This SDB defines projects that are subsequently assigned to various departments, which assume responsibility for the outcomes.

A big enabler for sustainability is the company's Environmental Management System. Novozymes assesses much of its supply chain based on sustainability metrics, including the assessment of suppliers based on quality, cost, and sustainable efforts.

Source: Novozymes. Two production workers in a warehouse in Franklinton, North Carolina. http://www.novozymes.com/en/news/image/Pictures/small-Production-new3.jpg

There are other ways that Novozymes drives sustainability into its supply chain. It has a "triple bottom line" approach to the environment, which enforces total cost reduction, stakeholder engagement, and real improvements in the environment/community. Sustainability metrics are part of every assessment for every supplier, as well as every business case. Suppliers go through in-depth audits on energy, pollution, safety issues, and labor conditions. These are tough criteria, and the bar is set very high.

The company's chief supply chain officer noted that "it is tough for suppliers to meet our minimum standards, but if they don't they are simply not considered for business. We will produce actions for them to comply with that can get them to qualify at some point in the future if they meet them. But on issues such as child labor, ethical behavior, and other elements, we simply will refuse to talk to them! We also emphasize their continuous improvement efforts on environmental performance, including how they assess THEIR suppliers. And logistics is a big part of this too. We ship tankers of chemicals around, and a leak is a massive deal, even if it is a couple of gallons. We will spare no expense on cleanup on any leak."

Novozymes' primary products are enzymes that are used in many products, including bread and baked goods, detergents, and textiles. The number of applications of enzymes is increasing steadily based on population growth around the world. The company's largest market is in consumer products, followed by food and beverage, bioenergy, agricultural feed products, and a small, but growing, presence in technical pharmaceutical products. Major customers include Procter & Gamble, Henkel, Church & Dwight in the home health care (HHC) space, Archer Daniels Midland, Abengoa, and Farmers Cooperatives in the biofuels/bioenergy production space, and formulators of baking ingredients, including Caravan Ingredients, AB Mallory, and Lalamold. They also have partnered with major customers, such as BASF, Procter & Gamble, Walmart, Tesco, Marks and Spencer, Best Buy, and Nike to upgrade sustainable content in their products. End-to-end sustainability isn't just a flippant phrase at Novozymes; it's a way of doing business.

In most of these markets, there is fairly steady growth of approximately five to seven percent annually, and most consumer product markets (with the exception of bioenergy) are relatively stable and mature. Novozymes hopes to continue to increase market share in these industries by continuing to develop new enzymatic applications for these markets. A big part of the company's strategy involves continuing to work alongside scientists in their customer's labs to develop new applications.

Estimating the total contributions of Novozymes' products to U.S. jobs is difficult, because it truly is a global company. Novozymes is the global industry leader in enzyme production, with almost 50% market share. The company produces enzymes at various facilities worldwide, including major facilities in the U.S. with almost 1000 employees (Franklinton, NC, Salem, VA, Davis, CA, Ames, IA, Milwaukee, WI, and Blair, NE), that are close to biofuels producers. However, the company also has plants in Denmark, China, and Brazil. Although enzymes can be produced in any location and shipped elsewhere, Novozymes has a mandate to try to produce products in markets where they see growth. Markets are split almost evenly between the U.S., China, and Europe.

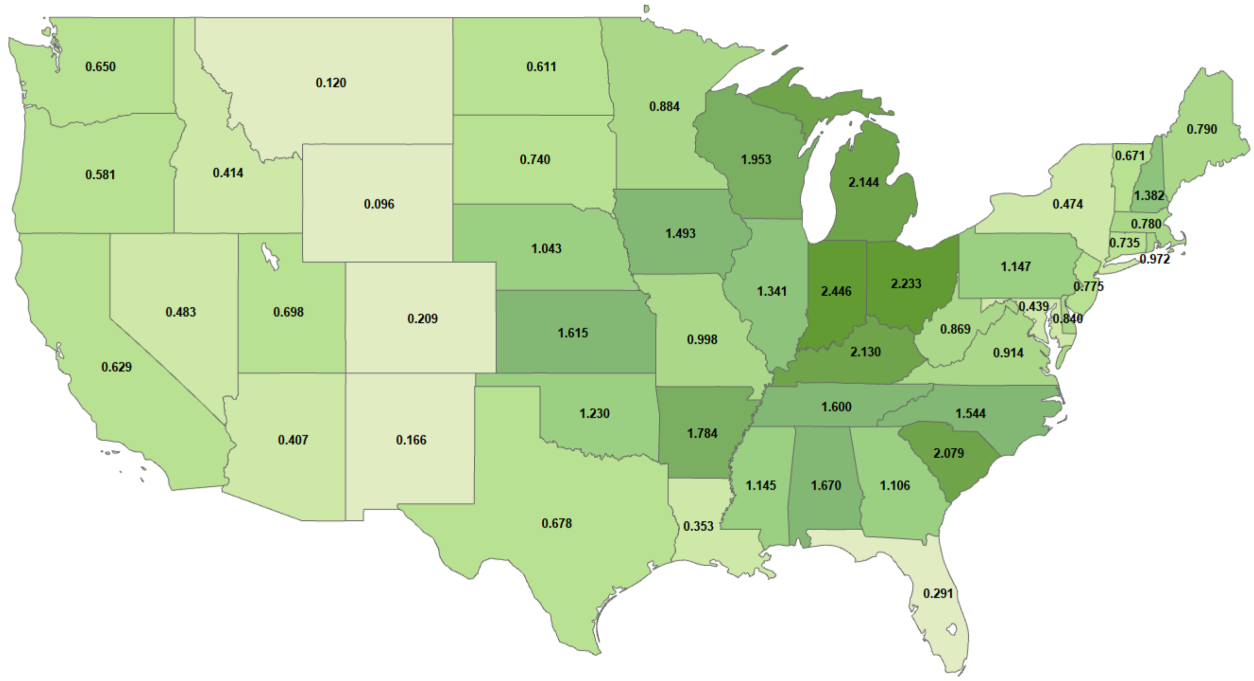
The major input into enzymes is sugar, which is purchased from Cargill. However, the company also is exploring the use of a genetically-modified corn product that is providing some very significant advantages related to genetically-modified seeds, which can provide environmental efficiencies through the use of such organisms. Scientists also are applying life cycle analysis to compare the amount of energy required to make an enzyme to the amount of energy saved when it is used. The cost savings when enzymes are used more than compensates for the energy used to make them in many cases, so, from a life cycle perspective, their production and use provide net reductions in the amount of CO_2 produced and in the amount of water used.

One of the biggest opportunities for sustainable impacts in enzyme production lies in the fact that the company's enzymes promote the use of biotechnology to render processes more efficient. So, a significant part of the company's value lies in collaborating with customers to drive innovative sustainable solutions. A second component of the advancement of sustainability that occurs at Novozymes is the company's improvements in productivity made possible by its intense focus on developing and using innovative processes. The ability of Novozymes' scientists to continually improve the types of micro-organisms as they are produced from growth stage to fully mature continues to evolve. As new enzymes that are more effective are discovered, their efficiency is often doubled. According to Novozymes, this means output doubles, while the volume of inputs going into production is also reduced, thus driving sales with lower material usage. Unlike the petrochemical industry, which seeks to optimize a fixed process, a biological system relies on improvement in the "software" to derive more outputs by improving the efficiency of the organisms at work in the system!

Novozymes also is one of the few companies that truly apply life cycle assessments to their product lines, customers, and suppliers. A team of analysts pursues various analytical models for all regions, evaluating levels of energy, water, and other elements. The company sponsors the World Wildlife Fund, and it has reduced its output of CO_2 by more than one billion tons. Its products also reduce waste. For example, packaged bread stays fresh for a longer period (two to three weeks rather than two to three days), which enhances shelf-life, reduces waste, and allows for delays in transporting products to grocery stores.

E. Bioplastic Bottles and Packaging

Figure 12: Location Quotients for the Bioplastics Bottles and Packaging



Drop-in solutions represent the single largest sector of the global bioplastics production. They are (partly) biobased, non-biodegradable commodity plastics such as PE, PET, or PP, and can be easily recycled along with their conventional counterparts.[49]

Major U.S.-Based Bioplastics Producers

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

Major U.S.-Based Bioplastics Users

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

Economic Statistics

Total value added to the U.S. economy in 2013:
$410 million

Type SAM Economic Multiplier in 2013:
3.64

Employment Statistics

Total number of Americans employed due to industry activities in 2013: 4,000

Type SAM Employment Multiplier in 2013:
3.25

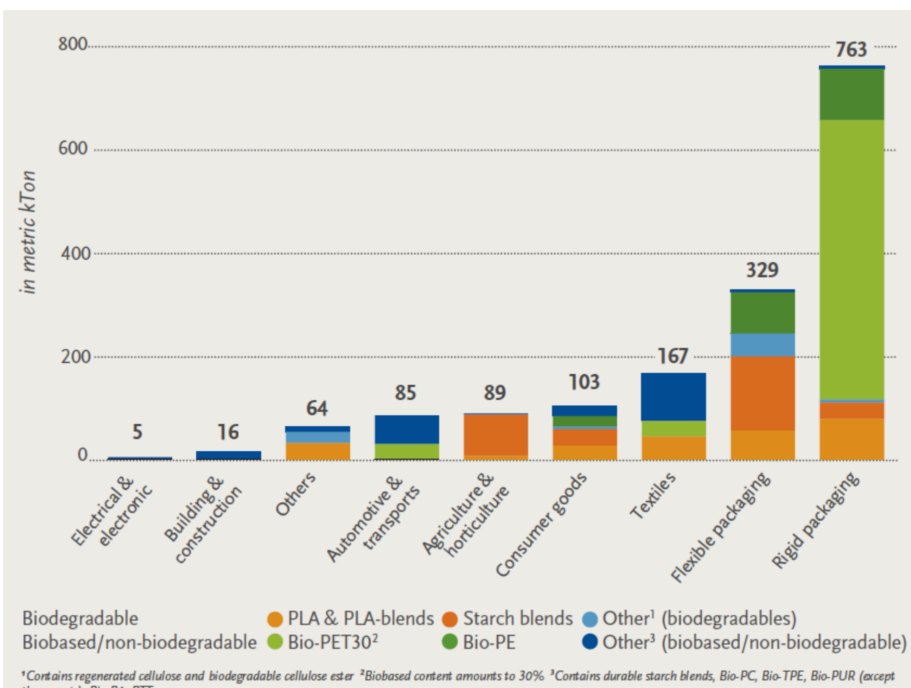
[49] European Bioplastics "European Bioplastics, Global PlantBottle use continues to grow," European Bioplastics website, http://en.european-bioplastics.org/blog/2013/06/21/global-plantbottle-use-continues-to-grow/, accessed April 2015.

Table 8. Distribution of Direct Value Added and Employment by Sub-Sector

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
195	32619	Other plastics product manufacturing	810	$60,625,000
188	32611	Plastics packaging materials and unlamented film and sheet manufacturing	240	$31,194,000
194	326160	Plastics bottle manufacturing	90	$12,065,000
189	326121	Unlamented plastics profile shape manufacturing	70	$7,529,000
		Totals	1,200	$111,412,000

Nike, Coca-Cola, Ford, Heinz, and Procter & Gamble joined efforts to form the Plant PET Technology Collaborative, the aim of which is to increase the use of biobased PET (polyethylene terephthalate) in the finished products. Coca-Cola launched its PlantBottle project in 2009. By May 2011, it was ready to start using the new bottles in the U.S., switching Dasani water bottles to 30% biobased PET and Odwalla juice bottles to 100% biobased high-density polyethylene (HDPE). In June 2015, Coca-Cola unveiled a PET bottle made entirely from plant-based materials. In 2011, PepsiCo announced they had developed a 100% biobased PET drink bottle made from switchgrass, pine bark and corn husks. The company is waiting to test large scale production and commercialization. Figure 13 shows the global production capabilities for biobased plastics by use category.

Figure 13: Global Production Capacities of Bioplastics 2013 by Market Segment



Source: European Bioplastics, "Bioplastics Facts and Figures," European Bioplastics website, http://en.european-bioplastics.org/wp-content/uploads/2013/publications/EuBP_FactsFigures_bioplastics_2013.pdf, accessed April 2015.

E1. Case Study: The Coca-Cola Company and PlantBottle™ Packaging

The Coca-Cola Company (TCCC) is a company that almost everyone in the world has heard of. In fact, TCCC has over 3,500 products, but most people struggle to list even 10 of them. Because of its ubiquitous presence in our daily lives, most people are unaware that TCCC is one of the largest bioplastics end-users in the world. TCCC’s PlantBottle™ packaging is the first-ever fully recyclable PET plastic made partially from plants (up to 30%). PlantBottle™ packaging is helping to reduce our dependence on fossil fuels and increasing our use of renewable materials.

There was an early push to explore the use of biopolymers and TCCC’s decision-makers realized that they needed to identify a polymer that could meet three important requirements: 1) it must be cost-competitive in the long-term, 2) it must meet the quality characteristics required by consumers (portable, shatter-resistant, resealable), and 3) it must be recyclable. It was recognized that it might not be possible to meet all three criteria in the short-term; however, it was assumed that promising alternatives could be developed over time to meet the criteria.

Initially launched in 2009, PlantBottle™ packaging is TCCC’s breakthrough packaging innovation —the first-ever fully recyclable PET plastic made partially from plants. PlantBottle™ material is made by converting the natural sugars found in plants into a key ingredient for making PET plastic. Since the material’s launch, more than 30 billion PlantBottle™ packages have been distributed in nearly 40 countries. The technology has enabled TCCC to eliminate more than 270,000 metric tons of CO_2 emissions—the equivalent to the amount of CO_2 emitted from burning more than 630,000 barrels of oil—and save more than 30 million gallons of gas.

Today, TCCC is using sugarcane and sugarcane waste from the manufacturing process. Both materials meet TCCC’s established sustainability criteria used to identify plant-based ingredients for PlantBottle™ material. These sustainability criteria include demonstrating improved environmental and social performance as well as avoiding negative impacts on food security.

TCCC plans to convert all new PET plastic bottles, which account for approximately 60% of its packaging globally, to

PlantBottle™ packaging by 2020. In addition, TCCC is working with biotechnology firms on a commercial solution for PET plastic made entirely from plant-based materials. The ultimate goal is a 100% renewable, responsibly sourced bottle that is fully recyclable. In 2015, TCCC unveiled a PET bottle made entirely from biobased materials.

From inception, TCCC envisioned sharing the PlantBottle Technology™, based on the belief that sustainable innovation can have a greater impact when others join the journey. In 2011, TCC licensed PlantBottle Technology™ to H.J. Heinz for use in its ketchup bottles. In 2013, Ford Motor Company announced plans to use PlantBottle Technology™ in the fabric interior of its Fusion Energi hybrid sedan. And in 2014, the first reusable, fully recyclable plastic cup made with PlantBottle Technology™ rolled out in SeaWorld® and Busch Gardens® theme parks across the United States.

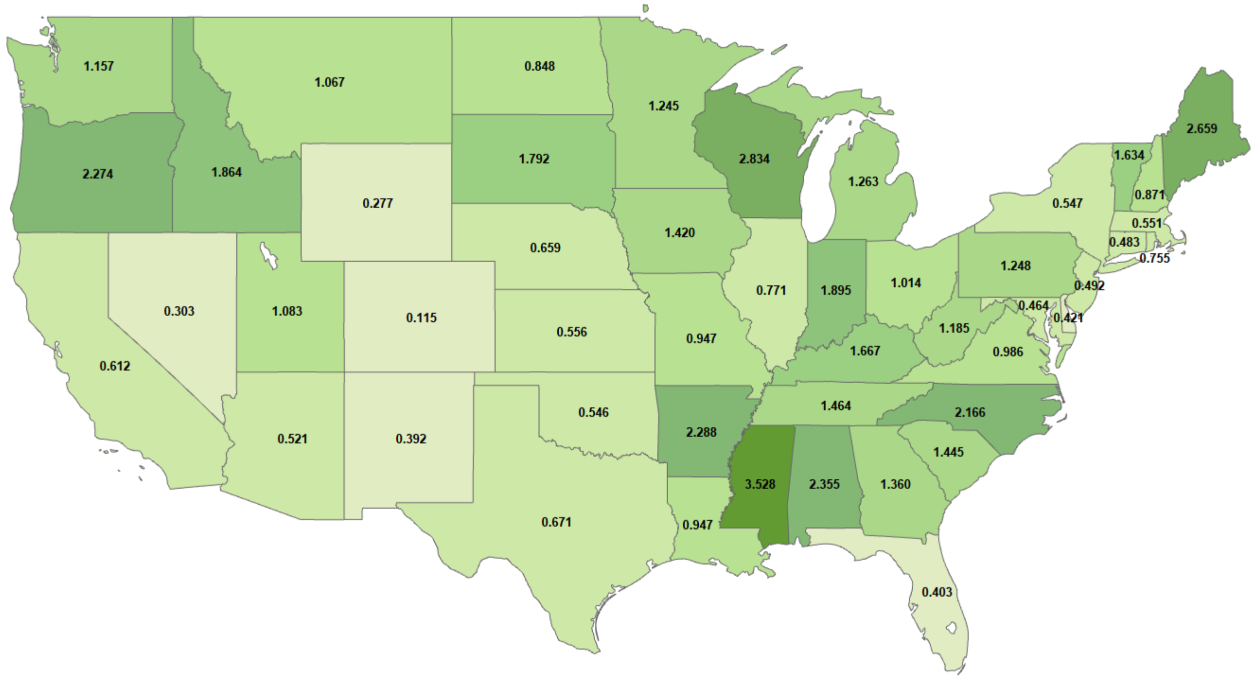
TCCC works hard to ensure that the environmental and social value of using PlantBottle™ packaging is better than traditional PET plastic bottles. TCCC works closely with third-party experts, like the World Wildlife Fund (WWF), to advance efforts to identify plant-based sugars that are responsibly grown and harvested. For example, TCCC joined seven major consumer brands and the WWF in founding the Bioplastic Feedstock Alliance to support the responsible development of plastics made from plant-based material. The Alliance will call upon leading experts to evaluate feedstock sources based on land use, food security, biodiversity and other impacts.

Additionally, TCCC and WWF have also partnered on a variety of sustainable agricultural initiatives, including creating an internationally recognized sustainable sugar certification program called Bonsucro.

The interior fabric of this Ford Fusion Energi was made with the same renewable material used to product Coke's PlantBottle™ packaging. Source: http://assets.coca-colacompany.com/5e/4d/2bb640bc4b32ae9edc8654f6bd5b/img-5152-v1.jpg

F. Forest Products

Figure 14: Location Quotients for the Forest Products Sector in 2013



One-third of the United States, i.e., 751 million acres, is forested. Privately-owned forests supply 91% of the wood harvested in the U.S. State and tribal forests supply approximately six percent and federal forests supply only two percent of the wood used by the forest products industry.[50]

<u>Major U.S.-Based Firms[51]</u>

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

<u>Economic Statistics</u>

Total value added to the U.S. economy in 2013: $333.6 billion

Type SAM Economic Multiplier in 2013: 3.54

<u>Employment Statistics</u>

Total number of Americans employed due to industry activities in 2013: 3,537,000

Type SAM Employment Multiplier in 2013: 3.85

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

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

Table 9. Distribution of Direct Value Added and Employment by Sub-Sector

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
149	32221	Paperboard container manufacturing	144,600	$13,811,000,000
368	337110	Wood kitchen cabinet and countertop manufacturing	111,200	$5,498,000,000
134	321113	Sawmills	89,900	$5,549,000,000
147	32212	Paper mills	72,600	$14,305,000,000
142	321920	Wood container and pallet manufacturing	62,800	$2,903,000,000
150	32222	Paper bag and coated and treated paper manufacturing	61,600	$7,064,000,000
369	337121	Upholstered household furniture manufacturing	58,800	$2,841,000,000
139	321911	Wood windows and door manufacturing	49,600	$3,170,000,000
141	321918	Other millwork, including flooring	40,400	$2,420,000,000
370	337122	Nonupholstered wood household furniture manufacturing	39,000	$2,071,000,000
136	321211, 321212	Veneer and plywood manufacturing	32,000	$2,075,000,000
137	321213, 321214	Engineered wood member and truss manufacturing	31,000	$1,381,000,000
152	322291	Sanitary paper product manufacturing	29,700	$7,274,000,000
148	322130	Paperboard mills	29,300	$5,994,000,000
145	321999	All other miscellaneous wood product manufacturing	24,800	$1,697,000,000
372	337127	Institutional furniture manufacturing	24,200	$1,453,000,000
143	321991	Manufactured home (mobile home) manufacturing	22,200	$1,279,000,000
151	32223	Stationery product manufacturing	21,200	$2,064,000,000
374	337212	Custom architectural woodwork and millwork	19,300	$1,263,000,000
373	337211	Wood office furniture manufacturing	19,100	$1,406,000,000
153	322299	All other converted paper product manufacturing	16,000	$1,477,000,000
138	321219	Reconstituted wood product manufacturing	14,800	$1,899,000,000
144	321992	Prefabricated wood building manufacturing	14,700	$927,000,000
140	321912	Cut stock, re-sawing lumber, and planing	14,500	$1,069,000,000
371	337125	Other household non-upholstered furniture manufacturing	11,600	$793,000,000
135	321114	Wood preservation	10,200	$1,180,000,000
146	322110	Pulp mills	6,300	$1,270,000,000
		Totals	1,071,300	$94,133,000,000

Industry Overview

The United States' forest resources provide a raw material for a myriad of products that are important to the economy. Many forest products are commonly known, such as copy paper, milk cartons, grocery bags, and furniture. Some paper products, such as diapers and bathroom tissue, are used daily. Others, however, are not as well known, e.g., those that are used in computer screens, time-released medications, food additives, viscose-based fabrics, and specialty chemicals. Since paper making processes were developed in the 1800s, the world's production level had grown to more than 400 million metric tons in 2011. China, the United States, and Japan are the top paper producers, accounting for half of the world's total paper production, with packaging accounting for approximately 33% and graphic paper accounting for approximately 50%. The United States' paper consumption of 70 million metric tons per year is second only to China, which uses 100 million metric tons per year.[52]

Forest Land Resources

Providing the raw materials of pulpwood, timber, and forest residues for the forest products industry requires land to grow trees, which are a renewable resource. Ninety-one percent of the wood that is harvested comes from privately-owned forests, six percent comes from U.S. State and tribal forests, and two percent comes from federal forests. Replanting and proper forestry practices are vitally important to ensure both the economic and environmental sustainability of forest products.

For trees to be a renewable resource, the rate at which they are harvested must not exceed their growth rate. After trees have been harvested, some of the land is replanted (about one million acres annually), and some of the land is allowed to regenerate naturally. The growth of timber in the U.S. exceeds the rate of harvesting, and this trend has largely existed since the collection of these data began in the early 1940s. Certification programs, including the American Tree Farm System, the Sustainable Forestry Initiative, and the Forest Stewardship Council, among others, encourage landowners and industry to manage forest resources responsibly and sustainably.

Despite the housing downturn and global recession of the last decade, the industrial roundwood equivalent of the U.S.'s consumption of wood and paper products still exceeded one cubic meter per capita, and it is slowly recovering to pre-recession levels. Conifer tree species in the Pacific Northwest and South supply lumber and wood composite products for use in residential and commercial construction. Lower quality eastern hardwoods are used in the manufacture of industrial products, such as railroad ties and pallets. Higher-quality hardwood trees are sawn into lumber, which is often the primary raw material for many other secondary products, such as furniture, flooring, and millwork. Both hardwood and softwood trees can be used in the production of pulp for paper products.

Major Companies

Within the forest products, paper, and packaging industries, International Paper holds the largest share of revenue followed by Kimberly-Clark and RockTenn. On January 2, 2015, RockTenn and MeadWestvaco entered into a combination agreement to create the world's largest packaging company with combined revenues of over $16 billion. With decreasing demand for graphic paper and other paper products, companies have curtailed production

[52] Statista, Statistics and facts about the global paper industry, Statista website, http://www.statista.com/topics/1701/paper-industry/, accessed April 2015.

periodically, shut down high cost production facilities and machines, and merged with other companies to reduce overall costs and to maintain prices that provide a reasonable profit. While the demand for certain grades of paper is decreasing in the United States, other markets around the world are growing with increased development and urbanization. The revenue of the forest products industry declined sharply during the economic downturn in 2009, but, to date, it has made a considerable comeback. It is now within one billion dollars of the revenue the industry received in 2008. It is likely that this trend will continue as the housing market recovers and as the economy as a whole continues to strengthen.

Manufacturing

Paper manufacturing is one of the most capital-intensive industrial processes, often requiring more than one billion dollars of capital investment for a fully integrated pulp and paper mill. The process of converting trees to pulp and paper requires large amounts of energy. The facility's energy demands are met in part by the production of renewable energy. This process involves chemical recovery that burns lignin for power and recovers the pulping chemicals, i.e., sodium hydroxide and sodium sulfate. The American Forest and Paper Association (AF & PA) reported that 66% of the energy used at AF & PA mills was energy generated from biomass. This renewable energy makes up 62% of the total biomass energy consumed by all manufacturing sectors. Recycling paper is another manufacturing process that breaks down paper into fibers that can be reused to make paper. However, the number of times the fibers can be reused is limited. Depending on the type of fiber and the grade of the paper, wood fibers can be used up to seven times. When degraded they must be removed as sludge. Recycling rates have increased since 1990, and they were reported to be 63.5% in 2013. The AF & PA's sustainability initiative, Better Practices, Better Planet by 2020, has set a goal of a 70% recycling rate by 2020.[53] Much of this recycled material is reused in paper products in the U.S., but approximately 40% of all recycled paper is exported to markets where a supply of fibers is needed. New and existing markets in Asia have been primary destinations for U.S.-sourced recycled fiber.

[53] AF&PA, Sustainability, AF&PA website, http://www.afandpa.org/sustainability, accessed April 2015.

G. Textiles

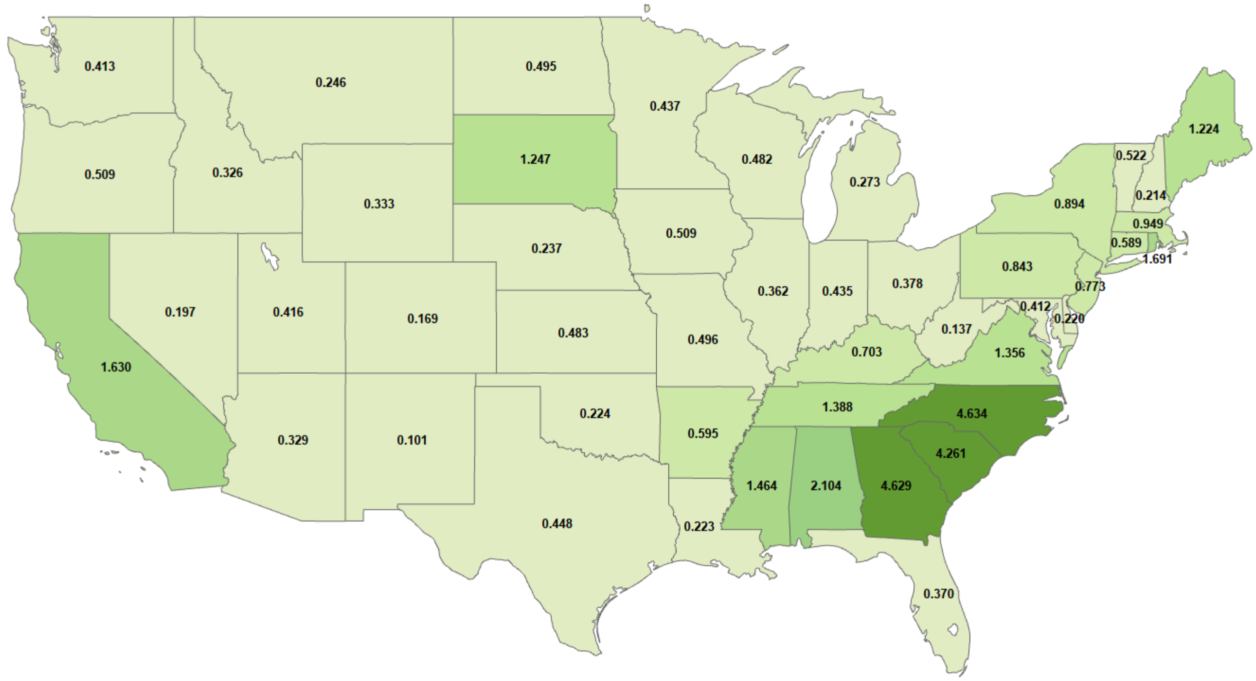


Figure 15: Location Quotients for the Fabrics, Apparel and Textiles Sectors (2013)

The U.S. apparel market is the largest in the world, comprising about 28% of the global total and has a market value of about $331 billion U.S. dollars.

Major U.S.-Based Firms[54]

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 2013: $33.9 billion

Type SAM Economic Multiplier in 2013: 3.53

Employment Statistics

Total number of Americans employed due to industry activities in 2013: 406,000

Type SAM Employment Multiplier in 2013: 2.47

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

Table 10. Distribution of Direct Value Added and Employment by Sub-Sector

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
126	31521	Cut and sew apparel contractors	19,100	$589,000,000
119	314110	Carpet and rug mills	14,600	$1,033,000,000
123	314999	Other textile product mills	14,400	$658,000,000
128	31523	Women's and girls' cut and sew apparel manufacturing	13,600	$1,009,000,000
112	31311	Fiber, yarn, and thread mills	12,400	$705,000,000
113	313210	Broadwoven fabric mills	12,200	$876,000,000
127	31522	Men's and boys' cut and sew apparel manufacturing	11,900	$605,000,000
117	31331	Textile and fabric finishing mills	11,300	$747,000,000
121	31491	Textile bag and canvas mills	11,000	$518,000,000
120	31412	Curtain and linen mills	9,000	$519,000,000
129	31529	Other cut and sew apparel manufacturing	5,900	$272,000,000
115	313230	Nonwoven fabric mills	5,400	$628,000,000
130	31599	Apparel accessories and other apparel manufacturing	5,200	$270,000,000
124	31511	Hosiery and sock mills	3,600	$158,000,000
114	31322	Narrow fabric mills and schiffli machine embroidery	3,500	$171,000,000
118	313320	Fabric coating mills	3,400	$310,000,000
116	31324	Knit fabric mills	3,000	$180,000,000
122	314991, 314992	Rope, cordage, twine, tire cord and tire fabric mills	2,800	$235,000,000
125	31519	Other apparel knitting mills	2,200	$122,000,000
		Totals	164,400	$9,606,000,000

The U.S. apparel market continues to be the largest in the world, representing 28% of the global share, i.e., $331 billion.[55] In 2010 the apparel manufacturing industry employed over 105,000 people; however, far more people are engaged in apparel manufacturing in Asia, and much of the sector has moved there due to the lower wages. The textile industry is one of the most important employers in the manufacturing sector, with more than 230,000 workers, representing two percent of the U.S.'s manufacturing workforce. This industry ranks fourth in global export value, behind only China, India, and Germany. U.S. exports of textiles increased by 12%, to $17.1 billion, from 2010 to 2012. More than 65% of the U.S.'s textile exports go to free trade agreement partner

[55] Statista, Statistics and facts on the Apparel market in the U.S., Statista website, http://www.statista.com/topics/965/apparel-market-in-the-us/, accessed April 2015.

countries.[56] According to news accounts, in 2013, companies in Brazil, Canada, China, Dubai, Great Britain, India, Israel, Japan, Korea, Mexico and Switzerland, and the U.S. announced plans to open or expand textile plants in Georgia, Louisiana, North Carolina, South Carolina, Tennessee, and Virginia. In 2013, nine textile firms in North Carolina announced plans to build or expand plants in the state, creating 993 jobs and investing $381 million.[57, 58]

[56] Select USA, The Textiles Industry in the United States, Select USA website, http://selectusa.commerce.gov/industry-snapshots/textile-industry-united-states, accessed April 2015.

[57] USA Today, Textile industry comes back to life, especially in the south, USA Today website, http://www.usatoday.com/story/news/nation/2014/02/05/stateline-textile-industry-south/5223287/, accessed April 2015.

[58] Select USA, The Textiles Industry in the United States, Select USA website, http://selectusa.commerce.gov/industry-snapshots/textile-industry-united-states, accessed April 2015.

G1. Case Study: Innovation in the Textiles Sector

In 2006, DuPont Tate & Lyle biobased products started their $100 million Bio-PDO™ (1, 3 propanediol) manufacturing plant in Loudon, Tennessee, a town with just over 5,000 residents. As the world's largest aerobic fermentation plant with a capacity of over 140 million pounds per year, the facility is an economic catalyst in the region. Bio-PDO has become a major biobased feedstock for companies that make various products, ranging from apparel to industrial fluids. In addition to its technical benefits in several manufacturing processes, it consumes 40% less energy and produces 20% less greenhouse gas emissions than the production of its petroleum-based counterparts on a pound-for-pound basis. One hundred million pounds of Bio-PDO will save the energy equivalent of 15 million gallons of gasoline per year, which is approximately the amount of gasoline required to fuel 27,000 cars for a year.

Bio-PDO was the recipient of the 2003 Presidential Green Chemistry Challenge Award, and it has built on a platform of other DuPont innovations. DuPont's Pioneer seeds are used to grow corn, some of which is used to produce glucose. This glucose is fermented using proprietary DuPont biotechnology to make Bio-PDO. After it is produced in Tennessee, Bio-PDO is shipped to customers around the world for use in the creation of biobased products, including personal and home care products, such as liquid detergents and industrial products, low toxicity anti-freeze and aircraft de-icing fluids.

However, DuPont's Sorona®, which is based on Bio-PDO, ranks as one of the most innovative and commercially-successful biobased products manufactured in the United States. DuPont's first biobased polymer plant is located in the small town of Kinston, North Carolina, which has about 21,000 residents.

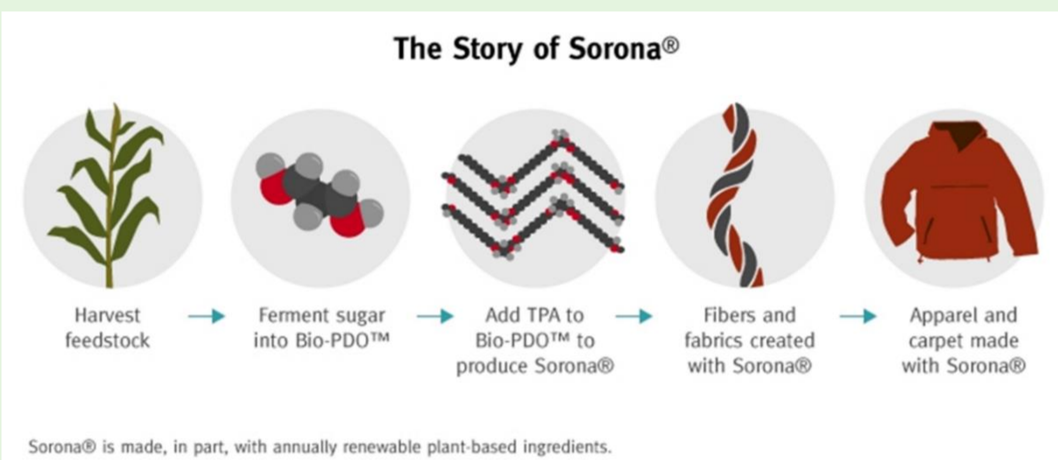
At the manufacturing plant in North Carolina, terephthalic acid is added to the Bio-PDO to produce Sorona, which is a 37% by weight renewable polymer. Sorona has a unique semi-crystalline molecular structure, which makes it a highly sought after bio-product, in part because the polymer has a pronounced "kink" in its backbone. Because of this structure, any fabric made with Sorona is able to withstand stress and completely recover its initial shape. In fact, you can safely stretch Sorona fabrics double or triple the distance that nylon can be stretched. Sorona is said to be softer and to have better dyeability than both nylon and polyester, which is of great importance to apparel manufacturers. For consumers, Sorona fabrics provide excellent washfastness, UV resistance, and eco-friendliness. In fact, Cintas, a leading manufacturer of corporate identity uniforms, uses Sorona in two of its key lines.

"Cintas is committed to identifying sustainable options that not only reduce our environmental footprint, but also enable our customers to do the same," said Kristin Sharp, Director of Design and Merchandising at Cintas Corporation. "Our partnership with DuPont Sorona provided the opportunity to develop the AR Red™ Suiting and Jay Godfrey collections, made with renewably sourced fiber, which provide customers with natural stretch, better color retention and wrinkle resistant garments while being environmentally conscious. Through the sales of these collections containing Sorona fabric, we were able to save the equivalent of 1,188 gallons of gasoline in 2014." In addition to apparel, Sorona is expanding rapidly into the global carpeting sector for both commercial and residential spaces. In its carpet section, Home Depot provides a wide selection of carpets made with Sorona that are marketed under the generic name of the fiber, Triexta. These carpets are marketed as permanently stain-resistant from the inside out, and they are very soft, highly durable, and fashionable with unlimited color and design options.

While still being economical for the consumer, carpets made with Sorona also have a lower environmental footprint. Production of Sorona polymer uses 30% less energy in manufacturing and produces 63% less greenhouse gas emissions than the production of traditional nylon 6.

"Sorona provides all the benefits of renewability without sacrificing the need for a versatile material that offers high performance and design freedom," said Simon Herriott, Global Business Director, Biomaterials, DuPont Industrial Biosciences. "We are seeing strong demand from consumers that value high biobased content without sacrificing durability and stain resistance."

Sorona is used by Toyota in Japan in the interiors of many of its vehicles, including the luxury SAI and the Prius α. In Australia and New Zealand, Godfrey Hirst produces carpets made with Sorona.



G2. *Case Study: Patagonia and Yulex – Finding Renewable Sources for Neoprene*

Source: Yulex Corporation

Patagonia is another organization with a strong culture of sustainable product development linked to the stewardship of its founder. It has established a three part mission: build the best product, cause no unnecessary harm, and use business to inspire and implement solutions to the environmental crisis. The company was founded by a rock climber, and it has grown into a worldwide business that makes clothes for climbing, skiing, snowboarding, surfing, fly fishing, and running.

Rick Ridgeway, Vice President of Environmental Affairs, makes it his business to constantly be on the lookout for ways to drive sustainability goals into every area of the business. He chairs an internal council with representatives from all areas of the business who advise the company on its sustainability goals. Patagonia has deeply embedded the concept of sustainability and a commitment to it in the organization, and it is constantly seeking to connect decision makers with outside resources that can help develop new ideas. For example, in 1996, Patagonia began using only organic cotton in its clothing.

One of these areas of focus is to continually work towards the goal of working with renewable materials. One of the most successful and prominent success stories in this area involves the development of wetsuits incorporating material produced by Yulex.

A wetsuit is basically made of foam rubber, which is laminated on one or two sides to a fabric, usually polyester or nylon in a jersey knit. The pieces are glued and/or stitched together to make a wetsuit, and then the seams can be sealed to prevent leakage. The foam rubber is made from polychloroprene rubber chips, commonly called neoprene. These chips are melted and mixed together with foaming (blowing) agents and pigment, usually carbon black, and baked in an oven to make them expand. When Patagonia first started making wetsuits, designers recognized that neoprene could be produced either from petrochemical feedstocks or from limestone, which is not a renewable material. However, they were not satisfied with this because limestone is a limited, non-renewable resource. A blog post in 2008 by Patagonia's design engineer Todd Copeland emphasized that "Limestone doesn't make a wetsuit more environmentally friendly. Push for new, innovative materials and construction methods, because we've got a long way to go before anyone has a true 'green' wetsuit."[59]

This post got the attention of Yulex, who contacted Patagonia's engineers with an idea for a replacement for petroleum or limestone-based neoprene. Yulex was working on leveraging the unique properties of the guayule plant, a hearty desert shrub native to the southwestern United States and northern Mexico. The two organizations began a collaborative, long-term research and development project to develop a wetsuit material from guayule rubber.

Production of guayule began early in the 1900s, as the early industrialists, such as Harvey Firestone and Henry Ford, sought to find a replacement for natural rubber when the South American rubber plantations were destroyed by leaf blight. The plant requires low inputs of water, nutrients, and pesticides, and it can be grown in arid climates. During their growth, the plants absorb and sequester carbon from the atmosphere. Guayule is harvested in a way that allows the plants' roots to stay in the ground for an average of four years, reducing the soil and carbon loss associated with constant tilling and replanting of a typical cropland. USDA's Agricultural Research Service (ARS) and National Institute for Food and Agriculture (NIFA) provided technical and financial support to develop the agronomics of the plant and possible commercial uses.

Patagonia worked for many years with Yulex, and, after considerable testing and development, identified a solution that incorporated a blend of the two materials for its new line of wetsuits. Guayule rubber is a renewable resource that provides better elasticity and softness in the finished material than traditional neoprene made from petroleum (or limestone), and it can be replaced faster than the product wears out. Growing guayule rubber is a low-impact agricultural undertaking, and the extraction and processing of the rubber uses little energy and few chemicals. Further, the Yulex processing facility uses far less energy than is used in the refining and processing of neoprene and its synthetic precursors.

A big part of the success story is that Patagonia shared this proprietary technology with other wetsuit competitors. This is also part of their overall culture of doing what is best for the industry. If all producers work towards using biorubber as the standard for manufacturing wetsuits, the volume of guayule harvested can reach a critical mass that will drive costs down, increase its use, decrease the use of petrochemically-derived rubber, and cause less harm to the environment. A core part of the Patagonia brand is its ongoing commitment to the promotion of environmentally-conscious materials and biobased feedstocks within a closed loop system.

Like other companies identified in this report, Patagonia has strict requirements for the use of new materials. The first and foremost qualification for a new material is its performance. Patagonia has a business model that promotes a commitment to seeking long-term durability of all apparel, because more durable products have a smaller adverse impact on the environment. Patagonia's key recipe for success is that materials be durable, environmentally preferred, and do no harm. Guayule is consistent with that recipe in that it functions well, lasts a long time, and is biobased.

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[59] Patagonia® The Cleanest Line, Green Neoprene? Patagonia® The Cleanest Line website, http://www.thecleanestline.com/2008/05/green-neoprene.html, accessed April 2015.

III. Sector Economics

A. Defining the Biobased Products Sector

As presented in *Why Biobased? Opportunities in the Emerging Bioeconomy*, the industrial bioeconomy is, "the global industrial transition of sustainably utilizing renewable aquatic and terrestrial resources in energy, intermediate and final products for economic, environmental, social and national security benefits."[60] This report focuses on the industrial biobased products sector, a sub-sector of the larger industrial bioeconomy. The biobased products industry includes the following major sectors of the U.S. economy:

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

Biobased products also are found within subsets of these major sectors, such as rubber and tires, toiletries, and printing and inks.

One of the limitations of undertaking this research is that, at present, no NAICS has been established for biobased products in the U.S. economy. 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 the U.S. business economy. This limitation is discussed further in Section V. However, the research team developed an extensive database of applicable NAICS codes, which 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 in which biobased chemicals exist. A complete listing of all the modeled NAICS codes used is provided in the front of each applicable section.

The next phase required the research team to develop a range for the biobased percentage of each sector, for example, what percentage is biobased chemicals in the total chemical sector? To accomplish this task, we analyzed the peer-reviewed literature; governmental and agency reports, both domestic and international; literature related to industry and trade organizations; and market intelligence reports. We also conducted interviews of representatives from industry, non-governmental organizations (NGO's), academia, and the government. Table 11 provides the percentages of biobased products in the overall economy.

Percentage of the Industry Comprised of Biobased Products

The following paragraphs discuss the approach that we used to develop the percentages for three of the seven sectors that are presented in Table 11.

Agriculture and Forestry

The "support activities" category in Table 11 includes cotton ginning, soil testing, post-harvest activities for crops, timber valuation, forest pest control, and other related support services for forestry. These activities were determined by the Census Bureau. The average figure of 14.4% for support activities across all sectors was derived based on the

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

Table 11. Percentages of Biobased Products within the Total U.S. Economy in 2013

Sector	Percent Biobased	Source
Agriculture and Forestry		
Cotton farming	100	
Forestry, forest products, and timber tract production	100	
Commercial logging	100	
Corn	2	USDA ERS
Oil seed farming to glycerin	0.6	USDA ERS
Sugar	1.7	Godshall, M.A. Int. Sugar J., 103, 378-384 (2001)
Support activities	14.4	Based on percentage of agriculture that is biobased, removed livestock
Biorefining		
Wet corn milling	2	Scaled on agriculture biobased percentage
Soybean and other oilseed processing	0.6	Scaled on agriculture biobased percentage
Fats and oils refining and blending	0.6	Scaled on agriculture biobased percentage
Beet sugar manufacturing	1.7	Scaled on agriculture biobased percentage
Sugar cane mills and refining	1.7	Scaled on agriculture biobased percentage
Textiles	40.87	White Paper on Small and Medium Enterprises and Japan (2012)
Forest Products	100	
Biobased chemicals	4	Current Status of Bio-based Chemicals, Biotech Support Service (BSS)
Enzymes	3.93	BCC Research Report (January 2011)
Plastic Packaging and Bottles	0.28	European Bioplastics, Institute for Bioplastics and Biocomposites, nova-Institute (2014)

Note: Where conflicting percentages were presented, the research team elected to utilize the lower, more conservative estimates. See the Recommendations section of this report for suggestions on increasing transparency and confidence levels in both federal statistical reporting programs and voluntary pre-competitive industry initiatives.

total support activities and the amount of output of corn, timber, and other products as a percentage of the total agricultural production that is biobased. We assumed that all sectors utilized the same support services equally. Certain sectors are worth noting here. In 2013, corn biorefineries processed 1.5 billion bushels of corn, which was about 10% of the U.S. corn crop.[61] The corn was used to produce starch (17%) sweeteners (53%) and ethanol (30%). The starch that was produced represented about two percent of the entire corn crop. Most of the starch was used to manufacture biobased products. We have not included the amount of ethanol

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

that we assumed went into other biobased products.

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, with the remainder 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)[62] 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)[63] estimated that the refining capacity in the U.S. is 17,830 thousand barrels per day, which is equivalent to approximately 6.508 billion barrels per year. Both of these numbers were current as of January 2015.

Textiles

About 40% of textiles are produced from biobased feedstocks, including cotton and rayon. Cotton, Inc. has estimated that 75% and 60% of summer and winter clothing, respectively, is produced from cotton.[64] Of this amount, textile manufacturing jobs accounted for only 148,100 jobs in 2012.

Information regarding the forest products, biobased chemicals, enzymes, and bioplastic bottles and packaging sectors is presented in greater detail earlier in this report.

B. Economic Growth Potential

In 2008, USDA published a report entitled, "U.S. Biobased Products Market Potential and Projections Through 2025," which was based on data from 2006 and focused on biofuels, biobased chemicals, and biobased end products. Utilizing the USDA report, in part, as a platform, the U.S.-based Biotechnology Industry Organization (BIO) indicated that U.S.-based jobs for renewable chemicals and biobased products will increase from approximately 40,000 jobs in 2011 for the biobased chemical/product sector, which represents three to four percent of chemical sales, to more than 237,000 jobs by 2025, which would represent approximately 20% of total chemical sales.[65]

We conducted several interviews at the BIO Pacific Rim Summit in San Diego in December 2014, and we identified several important trends that provide clues concerning the future growth of the biobased products sector. Some of the key issues that will impact growth in this sector are summarized below and are discussed in more

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

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

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

[65] BIO, BIO's Pacific Rim Summit Will Highlight Growth in California's Advanced Biofuels and Biorenewables Sector, BIO website, https://www.bio.org/media/press-release/bio%E2%80%99s-2014-pacific-rim-summit-will-highlight-growth-california%E2%80%99s-advanced-biofue, accessed April 2015.

detail in the segment-specific paragraphs following Figures 16 and 17, and at the end of this report in the sub-section "Emerging Trends in Biotechnology Innovation." Each of these factors will have a measurable impact on the rate of growth of the sector, thus, forecasting a range of growth is challenging and dependent on multiple factors.

1. New venture capital investment has slowed in recent years, but shows promise of increasing by five to 10% in the next five years provided that the right conditions are in place.
2. New technologies will be tied to readily available feedstocks, which could be in short supply going forward.
3. Successful technology development must be based on solid execution and business fundamentals.
4. Selection of the right supply chain technology partners is key, along with understanding the right market requirements for success.
5. Easy venture capital funding is no longer a reality, so long-term partnerships and alternative sources of funding are needed.

Figure 16: Estimated Growth in Employment from 2015 through 2020 for the Biobased Products Sector in the U.S. Excluding Enzymes

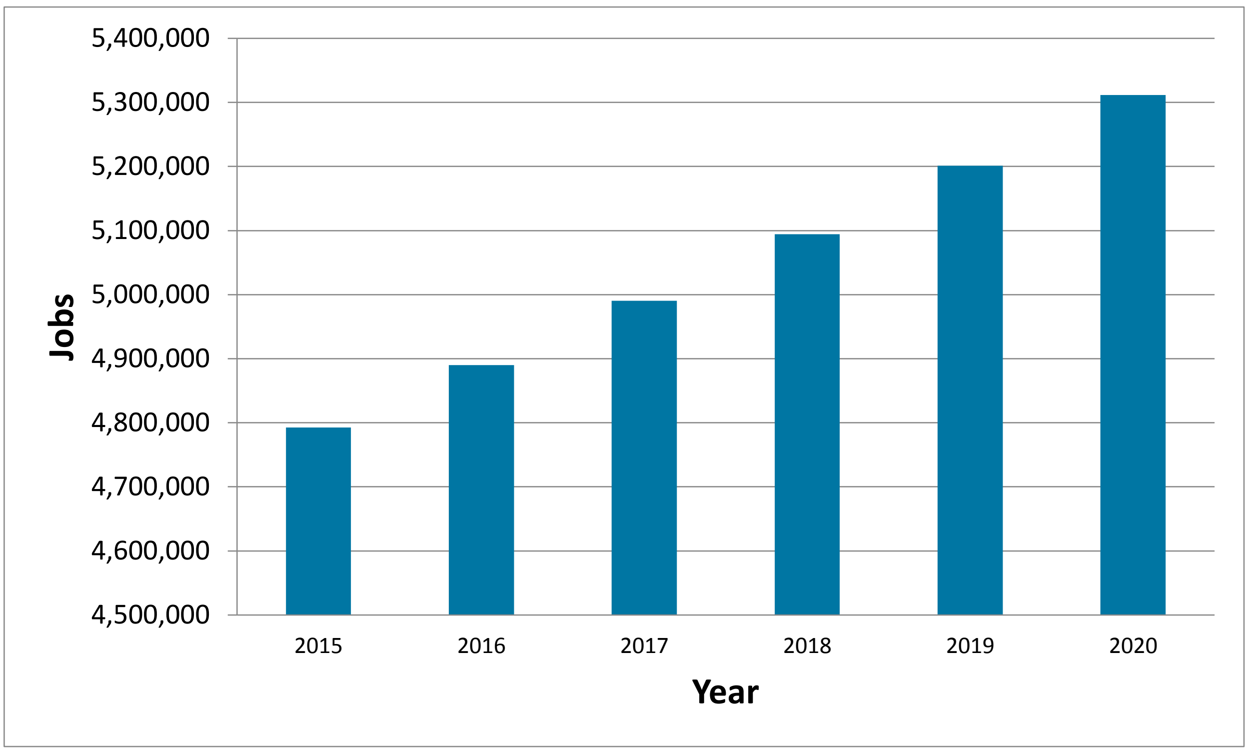
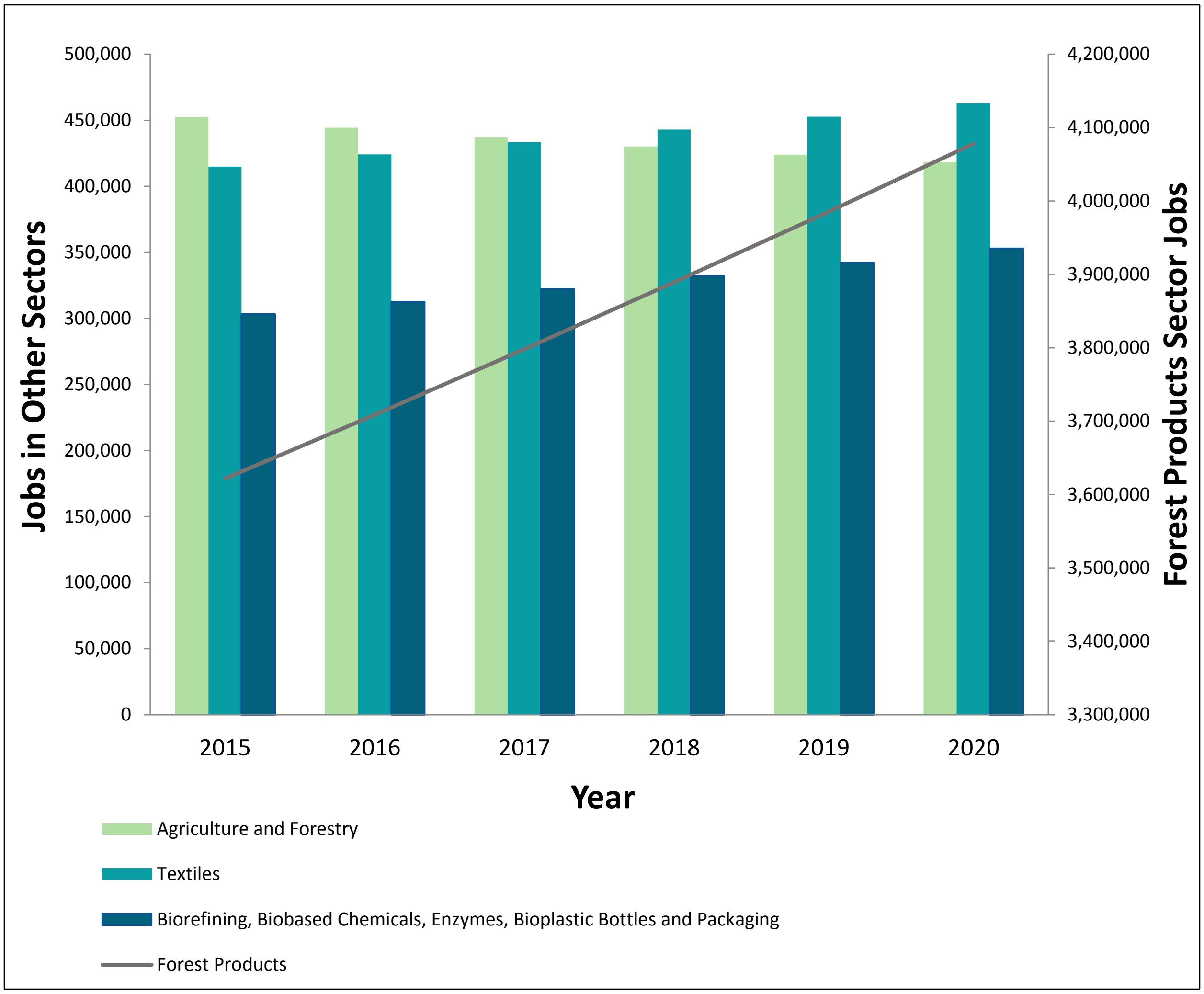


Figure 17: Estimated Growth in Employment from 2015 through 2020 in the Biobased Products Sector in the U.S.



AGRICULTURE AND FORESTRY

Cotton Farming[66]

As one of the world's oldest and most widely used fibers, cotton has much consumer appeal and is used in a variety of products such as clothing, home textiles, and personal care products. The cotton industry's revenue is boosted by shortages in supply, as was the case in 2010 and 2011, when India instituted a ban on cotton exports and large-scale floods adversely affected Pakistan's crop. The industry also is particularly sensitive to fluctuations in the exchange rate. U.S. industry exports have declined every year since 2012, due in part to an appreciation of the exchange rate and in part to the normalization of conditions in the global cotton market. However, exports as a share of revenue have declined from 77.5% in 2009 to an anticipated 69.0% in 2014. Conversely, a stronger dollar has driven the demand for imported cotton; the share of domestic demand that is met by imports has increased

[66] IBISWorld Industry Report 11192, Cotton Farming in the US, December 2014.

from 0.9% to an anticipated 3.8% over the same period.

The decrease in cotton prices after their artificial inflation in 2010 and 2011 has reduced profit margins from an estimated 14.1% in 2009 to an anticipated 11.5% in 2014. Over the next five years, the industry is expected to consolidate, and, barring any significant shocks (such as trade bans or floods), the industry's revenue is expected to decline at an annualized rate of 0.6% to $6.3 billion. Many operators who had entered the industry to benefit from the temporary boom are expected to leave as conditions normalize, which will reduce the number of people employed by the industry.

Forestry, Forest Tracts, and Timber Products[67]

The forestry products industry includes several segments that produce a wide range of intermediate and finished consumer-use products. From the initial logging operations and lumber production to the manufacture of products as diverse as toothpicks, kitchen cabinets, structural beams, and furniture, the forest products industry is subject to numerous economic factors. One of the largest of these economic drivers is the residential housing market. As the construction sector faltered during the subprime mortgage crisis and subsequent recession, demand for lumber to frame houses and support other structures dramatically declined. In recent years, the construction sector has started to recover as consumers gain employment, businesses earn more revenue and banks ease lending. In turn, greater construction activity has bolstered demand for lumber and other wood products, raising industry revenue. After dropping through 2011, revenue began to pick up and is forecast to increase at an annualized rate of 4.3% over the past five years, including a 4.8% increase in 2015, to total $29.3 billion. The following paragraphs present more detailed information for the timber production, wood paneling manufacturing, and paper products manufacturing segments, which are considered representative of the forest products industry.

Timber Production[68]

An important end market for timber is residential construction, which uses wood in the form of cut timber. The industry faced many difficulties in the wake of the recession, as demand from residential construction and the wider economy decreased and then slowly recovered through 2014. This recovery has once again driven up demand for standing timber and other industry services. In 2015, industry revenue is expected to increase by 5.1% because of the strong demand from the residential construction market. Housing starts are expected to increase as builders respond to pent-up demand for houses and consumers capitalize on moderate housing prices and low interest rates. However, the industry is expected to grow more slowly from 2015 to 2020, at an annualized rate of 1.6% to $1.6 billion in 2020. This slower growth rate primarily will be because of the stabilization of the residential construction and lumber markets. In addition, the industry's other major market, paper manufacturing, will continue its decline based on the move towards electronic media and e-books. Still, demand from other markets will increase, and this shows promise for partly offsetting the decreases in other parts of the supply chain. This positive outlook remains contingent on continued protection from Canadian imports and on favorable U.S. harvest conditions.

[67] IBISWorld Industry Report 32121, Wood Paneling Manufacturing in the US, December 2014.

[68] IBISWorld Industry Report 11311, Timber Services in the US, January 2015.

Wood Paneling Manufacturing
The wood paneling manufacturing industry produces wood panels and products from softwood and hardwood lumber and adhesives, such as resin. While the products can serve a variety of purposes, their largest market is in construction, particularly new homes. Therefore, demand for the industry's products depends largely on the number of housing starts and the value of residential construction. While housing markets are known to exhibit some volatility, during the past decade there was an unprecedented decrease in home construction because of the housing bubble and the subprime mortgage crisis, which resulted in an enormous decrease in the demand for wood paneling products during the recession. However, in the past five years, the industry experienced a small turnaround as the broader real estate market began to recover. While the real estate market is well below its pre-recession levels, housing starts have risen each year since 2010. Industry estimates forecast that between 2014 and 2019, the residential construction market will build on its recent turnaround, increasing the demand for wood paneling products. Even so, production numbers of wood paneling products are not expected to reach pre-recession levels. Over the next five years, revenue is forecast to rise at an average annual rate of 3.7%, reaching $21.9 billion by 2020. In particular, China is expected to move increasingly into the production of higher value added wood panel products, challenging revenue gains for domestic manufacturers and increasing global price competition.

Paper Product Manufacturing
Rebounding consumer spending and rising paper product prices have buoyed revenue for the paper product manufacturing industry over the five years to 2014. Industry operators convert purchased paper and paperboard into a variety of products, including playing cards, wrapping paper, cigarette papers and recycled paper insulation. Industry manufacturers also mold purchased pulp into egg cartons, food trays and other products. Demand for paper products used to package foodservice items limit revenue volatility for the industry, as these are relatively nondiscretionary products. Nevertheless, net sales for the industry fell at double-digit rates in both 2008 and 2009 due to faltering downstream demand for the industry's discretionary offerings. However, the industry's performance has improved over the five years to 2014 relative to these recessionary declines, with revenue expected to fall at an annualized rate of only 0.2% over the period to reach $4.3 billion.

Over the five years to 2019, industry revenue is forecast to decline at an annualized rate of 2.9% to reach $3.7 billion. While economic growth is expected to boost discretionary spending over the five-year period, the industry will continue to grapple with rising competition from imports and continued offshoring. Moreover, the industry will also be challenged by heightened environmental awareness, which will decrease demand for disposable paper products. In response, industry operators are anticipated to continue consolidating, with larger operators acquiring or merging with competitors. Additionally, paper product manufacturers are expected to respond to environmental concerns through technological advancements and the increased use of recycled material throughout the production process.

Corn[69]
As a result of legislation promoting the growth of biofuel production, corn has experienced a strong growth market for the past eight years. The Energy Policy Act of 2005 provided the initial sounding board for

69 IBISWorld Industry Report 11115, Corn Farming in the US, November 2014.

moving fuel demand away from foreign oil and initiated the promotion of using corn as a renewable energy source to make ethanol. Corn is the main source of ethanol, which provides natural sugars for fermentation. Ethanol production provides a large market for corn farmers, and their business provides the industry with an additional source of revenue. The Energy Independence and Security Act of 2007 increased the demand for corn further by setting the goal of producing 36 billion gallons of biofuel by 2022. These regulations created a significant new market demand for corn. As a result, industry revenue increased at an annualized rate of 4.2% to $63 billion from 2009 to 2014. Yields also were improved by the use of genetically modified seeds to produce high-yield crops that were resistant to diseases and pests. In 2011, tax incentives for ethanol were reduced to provide funds for other programs and the incentives were allowed to expire at the end of 2011. Even with these reductions, the demand for ethanol remained high because of the 2014 Renewable Fuel Standard (RFS) mandate and required corn farmers to produce more corn. In addition, the 2014 Farm Bill provided continuing financial support for corn farmers, despite its elimination of direct payments and the decision to limit the amount of assistance individuals are eligible to receive in a given year.

In 2013, U.S. corn production was about 15 billion bushels, 1.5 billion of which biorefineries processed. About 45% of the corn was used in livestock feed, 44% was used to produce ethanol, 10% was used in food (sweeteners and starch) and alcohol, and a small amount was used for planting.

Drought is another significant factor that affects the corn industry; in 2012, drought conditions caused exports to decrease by 31.5%, leading to a price spike. This was followed by a bumper crop in 2013, with a subsequent decrease in prices. Low corn prices continued into 2014 and demand is expected to decrease by 4.4% over the next five years.[70] However, the outlook may change as Federal Government mandates for renewable fuel in the 2014 Farm Bill will continue to support revenue for at least five years. In addition, many state governments have banned the use of methyl tertiary butyl ether (MTBE) in gasoline, leading to an increased demand for ethanol. Demand from emerging nations also will help increase U.S. exports.

Oilseed Farming[71]

In 2014, oilseed farmers were expected to generate revenue of $983.5 million, compared with about $40.0 billion generated by soybean farmers. The yield of soybeans is almost twice as much per acre as crops such as canola, flax, safflower, and sunflower. Soybeans can be used as substitutes for many products in the oilseed farming industry. Consequently, the price of soybeans, which are a much more widely produced crop, helps determine the demand for other oilseeds, such as canola and sunflower. When the price of soybeans increases, buyers are more likely to choose lower-cost industry products instead of soybeans. The record soybean crops in 2013 and 2014 increased the total supply of oilseed, which decreased the prices farmers received and resulted in decreased revenue for the industry. Biofuel producers also will continue to be an important source of demand for industry products. These crops will likely account for an increased portion of biofuel input over the next five years. Demand for oilseeds by biodiesel producers will remain strong due to the expansion of biofuel production targets and the RFS biodiesel

[70] For information on USDA projections for agricultural sectors through 2024, see http://www.usda.gov/oce/commodity/projections/index.htm

[71] IBISWorld Industry Report 11112, Oilseed Farming in the US, November 2014.

mandate. While it is unlikely that U.S. canola and sunflower farmers will reap the full benefits of expanded domestic biodiesel production, sustained demand will ensure that domestic prices remain high from 2014 through 2019. Because of the relationship of oilseed demand patterns to that of soybeans, experts anticipate an annual growth rate of one percent per year from 2014 through 2019.

Sugarcane Farming

The U.S. sugarcane farming industry has experienced spikes and drops in revenue over the five years to 2014. Sugar prices skyrocketed during the 2009 and 2010 growing seasons due to heavy rainfall that harmed crops in Brazil, the world's leading sugarcane producer. Consequently, the disruption in the global supply of sugar boosted demand for U.S. downstream sugar products. As a result of the ensuing price hikes, growers increased production, and revenue for the shot up from 2008 to 2011. However, increased production caused an oversupply of sugar, pushing down the commodity's price beginning in 2012. As a result of falling prices, industry revenue has fallen an annualized 5.6% to $864.6 million in the five years to 2014, including a 12.3% drop in 2014. Over the next five years, revenue is forecast to grow at an average annual rate of 2.3% to $967.5 million in 2019. However, an opportunity for the industry lies in commercial ethanol production. Currently, bagasse, a by-product of sugarcane processing, is used to self-sustain sugar mills in the United States. Thus, if ethanol production from bagasse is pursued on a larger scale, it will revive demand for the industry.

Forest Support Activities[72]

Operators in this industry assist downstream timber and logging operators in timber valuation, forestry economics, and forest protection. This includes estimation of timber, forest firefighting, forest pest control, and reforestation. Forestry activity has been increasing because of rebounding residential construction and renewed demand for lumber. However, key downstream markets, including timber tract operations, have reduced their need for support services because they prefer to undertake more operations within their increasingly vertically-integrated structures. Government agencies may outsource activities, and this is expected to increase modestly, leading to an anticipated forecast of 0.4% annually for forest support activities.

BIOREFINING[73]

Biorefining includes the manufacturing of basic chemicals (other than petrochemicals), industrial gases, and synthetic dyes and pigments. Key product groups include gum and wood products, ethyl alcohol, and other organic chemicals produced from non-hydrocarbon sources. The industry provides raw materials to different industries, such as plastic, paint, and adhesive manufacturing, and it has grown rapidly over the last five years, with an average annual growth rate of 7.1%.

The industry is classified into four main product refining groups, i.e., starch-based, cellulose-based, glucose-based, and synthetic-based groups. Biorefining is the primary source of bioplastics, which are being used for packaging products, such as beverage bottles, food containers, film, clamshell cartons, and loose fill used in shipping boxes. Bioplastics also are used in waste bags, carrier bags, and food service-ware, such as cutlery. Current niche markets include minor automotive parts and housings for electronic devices.

[72] IBISWorld Industry Report 11131, Timber Services in the US, March 2014.

[73] IBISWorld Industry Report 32519, Organic Chemical Manufacturing in the US, December 2014.

Ultimately, the biorefining industry is dependent on consumer spending, construction, and manufacturing activity. The level of demand experienced by the biorefining industry is influenced by several factors, including economic conditions, the price of oil, and the level of environmental awareness of consumers.

From 2010 to 2015, the demand for ethanol increased and is expected to increase further as exports, consumer spending, and consumer demand for gasoline increases. In 2005, the Federal Government passed the Energy Policy Act of 2005, encouraging the use of ethanol as a renewable fuel. In 2008, the Environmental Protection Agency (EPA) raised the minimum distillate requirement for gasoline and ethanol blends by more than 60.0%. The Energy Independence Security Act (EISA) of 2007 capped corn-based ethanol use in conventional biofuels at 15 billion gallons per year from 2015 until 2022. Ethanol is used in the manufacture of solvents, which are used in the production of coatings, detergents, cosmetics, and toiletries. In addition, acetyl intermediates, also produced by this industry, are used as starting materials for paints, colorants, adhesives, coatings, and other products. Demand is forecast to increase at a rate of 3.4%, although this could be influenced significantly by the price of oil, which could dampen this rate of growth.

Soybean Products[74,75]

At one time, soybeans were considered primarily as an imported commodity, with the majority of imports coming from China. However, the utility of soybeans as a primary source of protein and oil has led to their becoming a major crop, with 3.3 billion bushels yielding over $47.3 billion in value. They also have become a net export commodity to China, with over $28 billion of global exports in 2013.

Soybeans yield about 80% meal, 19% oil, and 1% waste. Approximately 98% of the soybean meal that is crushed is further processed into animal feed, and the rest is used to make soy flour and proteins. Approximately 70% of the oil fraction is consumed as edible oil, and roughly 22% goes into the production of biodiesel. The remaining eight percent is used for biobased products.

The United Soybean Board is one of best examples we found of an agricultural board that is documenting revenue growth for biobased products for its sector. This information is collected through a variety of sources, including interviews and analysis of USDA data, and requires a good deal of proprietary relationships and discussions that are classified and rolled up into appropriate categories of product, using the appropriate (but limited) number of producers.

The number of soybean-based products has increased significantly in the last 10 years. The total production of oil-based products is 1.5 billion pounds, beginning with a base of production of 0.5 billion pounds. This production includes glycerin and soap stock, which are co-products and by-products of the production process. This level of growth is in excess of the growth of the GDP, with some product categories showing minor growth year to year, while others were more dramatic.

Some of the markets are shrinking because of isolated technology trends. For instance, solvents and coatings will have significant

[74] United Soybean Board, "Think Soy: 2015 Soy Products Guide," United Soybean Board website, http://digital.turn-page.com/i/443195-soy-products-guide-2015, accessed March 2015.
[75] Interview with Jim Martin, Omni Tech International, March 13, 2015.

numbers of product launches, but may also be losing share of sales in their categories.

Sugar, Sugar Beet, and Sugarcane Refining[76]

The sugar processing industry produces and refines sugar from sugar beets and sugarcane, with the majority of production going to the food industry. The low price of sugar in 2012 and 2013, combined with the high level of duty-free imports from Mexico, reduced the industry's revenue over the past two years. The U.S. government provides loans, sets marketing allotment quotas, and determines tariff rate quotas to keep domestic sugar prices inflated. Experts forecast that revenue growth will slow down in the next five years, to an average annual rate of 1.4%, if world sugar prices remain low and low-cost imports continue to hurt the industry.

TEXTILES[77,78]

Textiles are created from fibers that are woven together to create products used for clothing, carpeting, furnishings, and towels. One of the main biobased sources for textiles is cotton. In 2012, rapid market growth in cotton textile products was driven by a large decrease in the price of cotton and increased demand from industry manufacturers. In addition, public protests against unfair working conditions in Bangladesh and supply disruptions resulting from electricity shortfalls in Pakistan also benefitted domestic knitting mills. Faced with shortages in supply from low cost offshore sources, retailers turned to domestic operators to fulfill their demand for apparel. This may be a short-term trend; however, as major apparel producers traditionally rely on manufacturing locations, such as Vietnam, Cambodia, Indonesia, and Thailand, which offer lower production costs than domestic operators. A return of textile manufacturing to the U.S. is expected; however, and this may help to increase domestic textile revenue. In general, forecasts suggest an increase of one to two percent over the next five years for domestic manufacturers.

ENZYMES

Enzyme technology has influenced almost every sector of industrial activity, ranging from the technical field to food, feed, and healthcare. Enzymatic processes are rapidly becoming better financial and ecological alternatives to chemical processes due to enzymes' biodegradable nature and cost effectiveness. Increasing global population and lifestyle trends have had a positive impact on the global demand for processed foods. With increasing pressure to feed the increasing population, the demand for enzymes in the food industry is expected to be strong over the next six years. In addition, the use of enzyme engineering serves as a great opportunity for companies operating in the global enzymes market, which, in turn, is expected to help the penetration of enzymes into fuel and chemical applications.

The industrial enzyme market is dominated by Novozymes, DuPont, and DSM. Maximum growth is estimated to be in the detergent enzyme market, which was valued at nearly $1.1 billion in 2013 and is estimated to reach $1.8 billion by 2018.[79] Animal feed is the second largest segment, with 10% compound annual growth rate (CAGR) during the forecast period. North America dominated the global market for enzymes and

[76] IBISWorld Industry Report 31131, Sugar Processing in the US, March 2014.

[77] IBISWorld Industry Report 31519, Apparel Knitting in the US, December 2014.

[78] OC Oerlikon Corporation AG Pfäffikon (2010) The Fiber Year 2009/10: A World Survey on Textile and Nonwovens Industry, Issue 10, Switzerland.

[79] BCC Research, Global Market for Industrial Enzymes to Reach Nearly $7.1 Billion by 2018; Detergent Enzyme Market to Record Maximum Growth, BCC Research website, http://www.bccresearch.com/pressroom/bio/global-market-industrial-enzymes-reach-nearly-$7.1-billion-2018, accessed April 2015.

accounted for 37.4% of total market revenue in 2013.[80] The growing demand for animals as a source of protein is expected to spur the demand for enzymes, such as proteases. Addition of these enzymes in animal feed is essential for the health and metabolism of the animals. The other key applications include detergents, biofuels, and industrial uses.

BIOPLASTIC BOTTLES AND PACKAGING[81]

Demand for the products of the bioplastics manufacturing industry increased from 2009 to 2014. Several factors have contributed to heightened demand, i.e., stronger economic conditions, large companies' joining the campaign for green packaging, and increasing environmental concerns pertaining to the use of petroleum-based packaging materials.

Because of their end uses, demand for plastics generally reflects overall economic conditions. Plastics are used extensively in the manufacturing of packaging materials and bottles, both of which tend to ebb and flow with the broader economy. When economic conditions are strong, more products are sold, all of which generally require some type of packaging; this, in turn, increases demand for bioplastics. Over the past five years, economic conditions have improved, as indicated by consumer spending increasing at an annualized rate of 2.6%. As consumers purchased more products after the recession, demand for bioplastic packaging increased. The negative implications of petroleum-based plastics, as well as the high carbon emissions associated with traditional plastics and their inability to biodegrade at a reasonable pace, have further fueled demand for bioplastics. In addition, new markets, such as the construction and medical segments, will open up new sources of demand. As a result of these positive trends, forecasters expect industry revenue to increase at annualized rate of 3.6%.

[80] Grand View Research, "Enzyme Market Analysis By Product (Carbohydrase, Proteases, Lipases, Polymerases & Nucleases) And Segment Forecasts to 2010," Grand View Research website, http://www.grandviewresearch.com/industry-analysis/enzymes-industry, accessed April 2015.

[81] IBISWorld Industry Report OD4512, Bioplastics Manufacturing in the US, October 2014.

IV. Environmental Benefits

The following section provides a brief overview of some of the environmental benefits that have been discussed and researched on a global basis. The benefits of using biobased feedstocks to support the biobased products industry is of great interest to researchers and stakeholders. The general public's perceptions and much of the literature, point to clear environmental benefits, including the reduction of greenhouse gas emissions. There a significant amount of on-going research aimed at developing a better understanding of the various trade-offs regarding water usage, biodiversity, land-use, and other environmental considerations. The results of this research have not reached the stage that would allow the presentation of any general conclusions. This research will be useful to both industry and governments as they develop innovative technological and organizational strategies.

Environmental Aspects of Biobased Products

Biobased products have been an important part of human history, from providing the first forms of heating and tools to advancing education by providing media for written communication. Many of these original uses of biobased products are still critical to society and many economies; 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 several examples of biobased materials that were developed prior to the rise of the petrochemical industry in the 1950s.[82,83,84] With 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 bioplastics, based on renewable polymers, have the potential to reduce the use of fossil fuels and the greenhouse gas emissions associated with that use.[85] To understand and quantify the environmental impacts of these biobased products, the life cycle assessment (LCA) framework defined in the ISO 14044 standard may be used. In the literature, this framework has been used to examine the life cycles of various biobased products and compare them to the fossil fuel-based

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[82] UK Monopolies Commission (1968) Man-made cellulosic fibres: A report on the supply of man-made cellulosic fibres. London: HMSO.

[83] Ralston BE and Osswald TA (2008) Viscosity of Soy Protein Plastics Determined by Screw-Driven Capillary Theometry; J Polym Environ 16(3): 169-176.

[84] Shen L, Haufe J, and Patel MK Product overview and market projection of emerging bio-based plastics. Group Science, Technology and Society, Copernicus Institute for Sustainable Development and Innovation, Utrecht University. The Netherlands.

[85] Pawelzik P, Carus M, Hotchkiss J, Narayan R, Selke S, Wellisch M, Weiss M, Wicke B, and Patel MK (2013) Critical aspects in the life cycle assessment (LCA) of bio-based materials – Reviewing methodologies and deriving recommendations. Resour Conserv Recy 73: 211-228.

products they could replace.[86,87,88]

The ISO 14044 standard has been beneficial in normalizing LCA methods and 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 surrounding biogenic carbon storage, emissions timing, direct and indirect land use change, and methodologies used for carbon accounting. The lack of commonly-used, widely-shared, and scientifically-sound methodologies to address these topics was noted by OECD (2010), Nowicki et al. (2008), Pawelzik et al. (2013), and Daystar (2015).[89,90,91,92]

[86] Shen L, Worrell E, and Patel M (2010) Present and future development in plastics from biomass. Biofuels, Bioprod. Biorefin 4I(1): 25-40.
[87] Groot WJ and 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.
[88] Weiss M, Haufe J, Carus M, Brandão M, Bringezu S, Hermann B, and Patel MK (2012) Review of the Environmental Impacts of Biobased Materials. J Ind Ecol 16(S1): S169–S181.
[89] OECD, "The Bioeconomy to 2030: Designing a policy agenda," OECD website, http://www.oecd.org/futures/long-termtechnologicalsocietalchallenges/thebioeconomyto2030designingapolicyagenda.htm, accessed April 2015.
[90] Nowicki P, Banse M, Bolck C, Bos H, Scott E. (2008). Biobased economy: State-of-the-art assessment. The Agricultural Economics Research Institute. LEI, The Hague.
[91] Pawelzik P, Carus M, Hotchkiss J, Narayan R, Selke S, Wellisch M, Weiss M, Wicke B, and Patel MK (2013) Critical aspects in the life cycle assessment (LCA) of bio-based materials – Reviewing methodologies and deriving recommendations. Resour Conserv Recy 73: 211-228.
[92] Daystar J, Treasure T, Reeb C, Venditti R, Gonzalez R and Kelley S (2015) Environmental impacts of bioethanol using the NREL biochemical conversion route: multivariate analysis and single score results. Biofuels, Bioprod. Biorefin DOI: 10.1002/bbb.1553.

Climate Change Impacts

There is extensive literature that deals with the role of biobased feedstocks as a renewable resource and their enhanced environmental performance as compared to non-renewable resources. LCAs are available in the literature that compare biopolymers and various petrochemical polymers; however, the results can be very disparate because of the lack of consistent LCA methodologies that are 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) as compared to the biobased alternatives.[93,94] The majority of studies focused only on the consumption of non-renewable energy and GWP and often found biopolymers to be superior to petrochemical-derived polymers. Additional studies that considered these and other environmental impact categories were inconclusive. It is also valuable to note that maturing technologies, future optimizations and improvements in the efficiencies of biobased industrial processes are expected as more is learned about these processes and products.

Carbon Storage in Biobased Products

Biogenic carbon requires additional accounting methodologies as compared to anthropogenic carbon emissions that originate from sources such as 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

[93] Song JH, Murphy RJ, Narayan R, Davies GB (2009) Biodegradable and compostable alternatives to conventional plastics. Philos Trans R Soc Lond B Biol Sci 364(1526):2127-39
[94] Shen L, Haufe J, and Patel MK Product overview and market projection of emerging bio-based plastics. Group Science, Technology and Society, Copernicus Institute for Sustainable Development and Innovation, Utrecht University. The Netherlands.

for a period of years, and the later burning or decompositions as a positive emission in the life cycle inventory.
2. Assume that biogenic emissions are carbon neutral and are excluded from life cycle inventories.

The benefits and issues surrounding temporary carbon storage and biogenic carbon are currently 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 horizon has the potential to reduce its GWP within a set analytical time horizon.[95,96]

The benefit created by temporarily removing carbon from the atmosphere depends largely on the analytical time horizon within which the GWP is calculated, which typically is 100 years. Benefits from storing carbon temporarily would generally be greater for short analytical time horizons, and the benefits would decrease as the time horizon 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 has released a draft regulation setting guidelines accounting for biogenic carbon emissions. Currently, this regulation is in the Notice-and-Comment Period.

[95] Levasseur A, Lesage P, Margni M, Deschênes L, and Samson R (2010) Considering time in LCA: Dynamic LCA and its application to global warming impact assessments. Environl Sci Technol 44(8): 3169-3174.
[96] Kendall A (2012) Time-adjusted global warming potentials for LCA and carbon footprints. Int J Life Cycle Assess 17: 1042–1049.

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

There are several methodologies that use an economic equilibrium model to capture 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, new land productivity levels, trade patterns, and the production of co-products. Despite the uncertainty and the issues associated with determining indirect LUC, it remains an important factor associated with biobased products.

Disposal
Biobased materials are often engineered to be biodegradable or they are inherently biodegradable in landfills. This feature potentially could reduce the amount of land required for landfills. The portion of biobased product carbon that does not decompose will remain in the landfill indefinitely, so the landfill can serve as a carbon sink. This permanent capture of carbon that was once in 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 unknown future of a product when it is created.[97] End of life LCA modeling also is sensitive to the biogenic accounting methodologies that are used, as discussed earlier.

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, as watersheds and aquifers have very specific individual characteristics, which can vary greatly.

[97] Pawelzik P, Carus M, Hotchkiss J, Narayan R, Selke S, Wellisch M, Weiss M, Wicke B, and Patel MK (2013) Critical aspects in the life cycle assessment (LCA) of bio-based materials – Reviewing methodologies and deriving recommendations. Resour Conserv Recy 73: 211-228.

A1. Case Study: Water Use Reduction

DuPont's PrimaGreen® Biobased Enzymes can reduce water use by 70% in the Cotton Textiles Sector.

A DuPont representative said that using DuPont's biobased enzymes as a replacement for traditional chemicals in cotton textile preparation can reduce water use by 70 % and energy use by 27%. A collaborative trial was conducted by DuPont Industrial Biosciences and Pacific Textiles Limited, a Hong Kong-based fabric manufacturer, using DuPont's PrimaGreen biodegradable enzymes as an alternative to caustic chemicals. DuPont Industrial Biosciences' Vice President John P. Ranieri said the trial confirmed the results from an earlier lab study DuPont conducted with the industry group, Cotton Incorporated.

The results of the study indicated that, in addition to reducing the water and energy requirements, the biobased enzymes reduced the steam required by 33% and total production time by 27%. In this trial, the cotton knits produced showed good whiteness values, better removal of motes, and maintenance of the fabric's strength and weight. In addition, the cotton knits were receptive to dark, medium, and light shades of dye. According to the company, the PrimaGreen enzymes helped save energy by allowing the preparation of the textile to occur at much lower temperatures. DuPont's biobased enzymes also saved water by enabling the same water bath to be used for multiple steps in the production process.

V. Recommendations

The following recommendations are based on researching many data sources and literature reviews, conducting individual and group interviews through conference proceedings, and individual meetings with representatives from the U.S.-biobased products industry as well as other non-governmental organizations. These recommendations are intended to support the continued growth of the U.S. biobased products industrial sector and increase economic growth and job creation throughout the United States. These recommendations reflect the opinions of the authors of the study based on their research and interviews. They do not necessarily reflect the opinions of the USDA.

A. Government Purchasing and Tracking

Federal agencies are required to purchase biobased products designated for mandatory federal purchasing under the BioPreferred® program, except as provided by Federal Acquisition Regulation (FAR) Part 23.404(b). In general, federal agencies are required to give preference to qualified biobased products over traditional, non-biobased alternatives when purchases exceed $10,000 per fiscal year, as prescribed by Title 7 of the U.S. Code of Federal Regulations section 3201.3.

In addition to the mandatory federal purchasing initiative, the 2002 Farm Bill authorized USDA to implement an initiative to certify biobased products that are deemed eligible to display the "USDA Certified Biobased Product" label. The presence of the label indicates that the products have been third-party tested and verified for biobased content, thus meeting the established minimum biobased content requirement for the product category applicable to that product. The BioPreferred program was reauthorized and expanded under subsequent U.S. Farm Bills in 2008 and 2014. Increasing the visibility of the USDA Certified Biobased Product label is critically important.

In addition to the BioPreferred program, there are other government drivers in the biobased economy. For example, on March 19, 2015, President Barack Obama released Executive Order 13693: Planning for Federal Sustainability in the Next Decade,[98] which includes provisions to increase federal agency accountability for achieving qualified biobased product purchasing requirements. Federal agencies are asked to establish annual targets for the number of contracts awarded with BioPreferred and biobased criteria and for the dollar value of BioPreferred and biobased products to be reported under those contracts. Federal agencies also are asked to ensure that contractors submit timely annual reports of their BioPreferred and biobased purchases.

NAICS

NAICS does not provide an effective means of tracking the economic and job implications of the biobased products sector in the United States. This results from a lack of industry-specific codes that were representative of the biobased products sectors of the economy. Many economists and industry groups recommended that NAICS codes be developed for biobased products and that reporting requirements be established to allow more effective tracking.

[98] The President, "Executive Order 13693 – Planning for Federal Sustainability in the Next Decade," Federal Register website, https://www.federalregister.gov/articles/2015/03/25/2015-07016/planning-for-federal-sustainability-in-the-next-decade, accessed April 2015.

B. Credits and Funding

Production Tax Credits and Other Tax Incentives

Common themes that exist among all of these policy recommendations are encouraging investment and creating incentives to reduce the cost of capital that drives innovation. Venture capital lenders often demand premium rates or large shares of the business, so identifying alternative approaches for funding investments is important. As noted during the BIO conference in December 2014 in San Diego, California, investment levels are at one of the lowest points in the last few years because of delays in plant construction and failure to achieve benchmark yield rates. A common theme that emerged in our interviews was that the only way that biobased products will penetrate markets is if production can be effectively scaled, which is difficult to do because economies of scale are often working against biofuels given the petrochemical alternatives. In many cases, an 80% capacity threshold is required to overcome profitability hurdles. The implication is that specialized and niche markets should be targeted, e.g., by focusing on synthetic chemistry to convert biofuels to alternative specialty chemicals, such as solvents, food additives, palm oil acid, and others. Support in the form of production credits, tax incentives, and specific investment incentives are increasingly important, and they appeal to potential investors.

Appropriate Funding

Title IX Energy Section 9002: Biobased Market (i.e., the BioPreferred program) of the 2014 Farm Bill authorizes $3 million in "mandatory" fiscal year (FY) funding from 2014 to 2018, which, because of required budget sequestration of 7.3%, has resulted in only $2.78 million of available funds during that time period. The bill also authorizes "discretionary" funding to be appropriated in the amount of $2 million per year from FY 2014 to 2018. However, Congress has not appropriated the discretionary funding, which is vital to supporting programs that can grow the U.S. biobased products industry and create more American jobs. There were strong voices from major U.S. companies, as well as from small and medium enterprises, urging Congress to appropriate the discretionary funds.

As presented in our recommendations section, mandates to collect data from federal agencies on biobased purchasing is very recent and the data do not exist to quantify the growth of the BioPreferred Program. Nor are there NAICS codes that make it easier to track the economic value of biobased products. However, there are very strong signals that indicate the increased consumption of biobased products. These include the voluntary participation of over 2,500 companies, representing about 20,000 products in the program. In addition, interviews with retailers, brand, manufacturers, and major industry consortia present their strong interest in purchasing and selling biobased products that meet the BioPreferred Program's requirements.

USDA Biorefinery Assistance Program

The USDA Biorefinery Assistance program, was recently expanded to include facilities producing biobased chemicals and biobased products.

The 2014 Farm Bill provided support for these programs, with well-developed administrative regulatory rules, particularly for the Biorefinery Assistance program. The prior version was strictly for advanced biofuels, and the 2014 Farm Bill expanded it to include biobased products and biobased chemicals. It is important to understand that a biobased product economy will not operate independently from the biofuels program in standalone facilities; the structure of the supply chain is very similar to that of the petrochemical industry. In the past, if a biorefinery produced anything but biofuels, it did not qualify for support under the Farm Bill. Continued support for the biorefinery program in the long-term will be required to effectively support the sector.

Fund and Administer the USDA's Biomass Crop Assistance Program (BCAP)

The biomass crop assistance program is a critical component that supports the growth of cellulosic non-food crops. The farming community needs assurance that crops will yield a profit. Some biomass crops take one to five years of lead time, and this program provides an assured market. Also, the mandatory funding of the program will continue the support it needs. Part of the debate concerning cellulosic fuels versus other products can be eliminated by programs such as the BCAP.

Promote and Increase in Government and Private Sector Purchasing of Biobased Products

Many individuals in our interviews emphasized that the key to stimulating growth and participation in the non-fuel biobased products sector is a reliable and robust purchasing commitment from the Federal Government. If manufacturers assume the risk to produce biobased products mainly because of the requirements and specifications set forth exclusively for consumption by the Federal Government, the Federal Government in turn, should support these products, thereby providing them with a "jump start."

The biobased sector should have the same playing field in the federal bioeconomy strategy that exists in Europe. The European Union has established policies to provide assistance to its agricultural industry through a variety of programs.[99]

In Europe, Canada, the United Kingdom, and certain countries in Southeast Asia (e.g., Malaysia and Thailand), strategies focused on building biorefineries are being promoted as part of bioeconomy policies.[100,101]

The industry is truly in its infancy, and at this point, these new products are, for all intents and purposes, "Custom Made" for the Federal Government, so they should be supported by the government. One way to ensure that this happens is to create awareness of the sector's products. At this stage, "non-fuel biobased products" are virtually unknown to most people along the supply chain, including wholesalers, retailers, distributors, FSSI contract holders (sellers), federal buyers, and most importantly, end users. Likewise, awareness in the private sector is of particular importance because compliance is a matter of choice.

If the Federal Government is a reliable customer for these products, they will be produced and efficiently distributed, demand will be met, and the industry will thrive.

The industry as a whole needs to be more focused on articulating "What is bio?" and "Why buy bio?" up and down the supply chain. For example, the Department of Defense considers the biobased products industry to be a "Matter of National

[99] European Commission, Horizon 2020, European Commission website, http://ec.europa.eu/research/bioeconomy/h2020/index_en.htm, accessed April 2015.
[100] European Commission, Research & Innovation: Bioeconomy, European Commission website, http://ec.europa.eu/research/bioeconomy/e-library/index_en.htm, accessed April 2015.
[101] U.S. Department of Commerce, International Trade Administration (ITA), ITA website, http://www.ita.doc.gov/td/health/malaysia_biotech05.pdf, accessed April 2015.

Defense," which is a compelling reason to buy biobased products. Better education of sellers, buyers, and consumer/end users alike will be required. Likewise, the extent of compliance with prescribed programs must be measured to ensure that the sector's actions reflect the Federal Government's priorities.

Fund and Administer USDA/DOE Biomass Research and Development Program
As noted, the initial focus of the biomass program was producing cellulosic ethanol. Emphasis is shifting to new startup technologies, such as algae-based fuel and green technologies.

We must work towards promoting the enactment of tax legislation for the production and use of biobased chemicals in the forms of the Production Tax Credit (PTC), Investment Tax Credit (ITC), Master Limited Partnership (MLP), and Research & Development (R&D) tax legislation.

Based on the current definition, the cellulosic second-generation biofuels have a production tax credit that expires, but they currently have a credit through the renewable category. In the biofuels industry, a production tax credit may be more beneficial, and a flexible PTC/ITC allows investors to choose an approach that aligns best with each investment and business plan. The biofuels and biobased chemicals communities are seeking to get this type of flexibility. Oil industries have a tax status known as a MLP that allows companies to define business partners and liabilities that are favorable. The MLP could be opened up to renewable energy companies, allowing them to derive improved investment outcomes.

Ensure that Biogenic Carbon is treated as Carbon Neutral in EPA's Carbon Accounting Framework
EPA is developing some standards for general accounting to develop a carbon-accounting framework. The real interest is that, currently, the carbon accounting framework has low carbon fuel standards, and it does not treat biobased carbon feedstocks as neutral. The biobased products industry believes this should change and an iterative framework discussion is underway.

Incentivize Renewable/"Green" Chemistry in TSCA Reform Legislation
The objective of the Toxics Substances Control Act (TSCA) is to allow EPA to regulate new commercial chemicals before they enter the market, to regulate existing chemicals when they pose an unreasonable risk to health or to the environment, and to regulate their distribution and use. Some kind of reform of TSCA relative to biobased chemicals and renewable specialty programs, as well as recognition for biobased feedstocks is important.

Legislation Improving Logistics Infrastructure to Support Biobased Production
Many people fail to connect biobased products with the biofuels industry even though they are directly connected, especially with respect to the movement of goods in the supply chain. The biomass program relies on rail and infrastructure to support the value chain and to connect the two parts of the industry.

C. Emerging Trends in Biotechnology Innovation

We conducted a number of interviews at the BIO Pacific Rim Summit in San Diego in December 2014 and identified several important trends that are worth discussing, and that provide clues concerning the future growth of this sector. Some of the key messages that emerged are listed below:

1. New venture capital investment has slowed in recent years, but shows promise of increasing by 5 to 10% in the next five years provided that the right conditions are in place.
2. New technologies will be tied to readily available feedstocks, which could be in short supply going forward.
3. Successful technology development must be based on solid execution and business fundamentals.
4. Selection of the right supply chain technology partners is key, along with understanding the right market requirements for success.
5. Easy venture capital funding is no longer a reality, so long-term partnerships and alternative sources of funding are needed.

Trend 1: New venture capital investment has slowed in recent years, but shows promise of increasing by 5 to 10% in the next five years provided that the right conditions are in place.

One of the biggest potential areas for the future of biobased products and the bioeconomy lies in the development of new and emerging technologies that utilize new potential feedstocks. According to Lux Research[102], the trajectory of venture capital investment in the biobased materials chemistry industry has gone through two distinct peaks. As the pioneering startups reached their first milestones in 2007, venture capital investment peaked at $907.7 million. Following this peak in 2007, the prolonged 2008 global market crash resulted in venture capital investment of just $569 million in 2009. Venture capital investment levels recovered in 2010, reaching an all-time high of $1.3 billion in 2011. Then, they decreased to $1.1 billion and $763.6 million in 2012 and 2013, respectively. Another wave of revitalization occurred in 2014, with projected total investment for the full year approaching $1 billion.

Looking to the future, there are a number of new sectors that have begun to emerge and will continue to do so in the next few years. A Lux Research report suggests that gas feedstocks, including algae, are receiving the bulk of new venture capital funding, even though they account for less than one percent of total biobased materials and chemicals capacity today. These include feedstocks that convert gaseous feedstocks using catalytic, fermentation, and algal technologies. First generation sugar conversion technologies are in second place with 31% of venture capital funding. Biobased oil and waste feedstocks were third, with 11% of venture capital funding. The high cost of feedstock often is problematic and prevents developers from reaching cost parity with petroleum. Other research results provided by Lux indicates that 344 metric tons of intermediate feedstocks are consumed overall to produce fuels and chemicals, of which 265 metric tons are sugar-based feedstocks, followed by vegetable oil.

Lux Research also reported that funding for drop-in products is about 60% of the total investment, with 39% of products having improved characteristics over their

[102] Lux Research, Dynamics of Venture Capital Funding in in the Biobased Chemicals Industry, September 2014.

predecessors. One example is Avantium, which received strong backing from Coca-Cola, Danone, and ALPLA.

Trend 2: New technologies will be tied to readily available feedstocks, which could be in short supply going forward.

North and South America are straining their sugar crops to make ethanol. About 37% of North American sugar crops are being used for ethanol, and about 27% is being used in South America. The largest consumers include companies such as BioAmber, Solazyme, and Amyris. As a result, it is important to think about aligning the right technology with the right feedstocks. Early stage producers are often naïve about the real costs of cellulosic biomass, and because it may be waste, they mistakenly assume that these feedstocks are free. However, research shows that the average cost for waste feedstock is $80 per metric ton, which is reachable. Costs may be as much as $160 per metric ton, which in this case, was a Chinese company that was using used furniture as a feedstock.

Productive technologies will seek to exploit plentiful feedstocks. For example, methane is an advantaged feedstock that does not vary based on the weather. Biotechnology has unlocked the potential of methane, which can be sourced from waste and renewables. Methane also has high potential for use in validated lactic acid production.

Calysta has established partnerships between different technology providers, feedstock producers, equipment manufacturers, investment banks, and product market providers to build partnered supply chains. The company is seeking to build a single cell protein plant to produce pellets for the animal feed industry to support the world's growing appetite for protein-based diets.

Another innovative example that considers natural feedstocks is Yulex, which has established the emergence of guayule natural rubber as an alternative feedstock to produce natural rubber from an alternative biobased source. Guayule is a plant that is indigenous to the Chihuahua Desert and that has been imported and grown in the United States. It was two years before the plants could be harvested, but they used little water, and rubber was harvested from the bark of the plant. Producing natural rubber from its traditional source is a highly capital-intensive process and requires 8 to 10 years to tap a tree. Yulex utilized genetics to determine how to expedite the growth and productivity of guayule, and this enabled them to double the yield of rubber per acre by using modern genomic tools. Yulex's rubber still sells at a premium, but certain brands are targeted, such as Patagonia wet suits and other companies that are willing to purchase from this alternative biobased feedstock.

Trend 3: Successful technology development must be based on solid execution and business fundamentals.

Many of the emerging biotechnology companies from 2011 to 2012 have seen their stock prices drop significantly due to the challenges these companies encountered in scaling up their initial plants and technology platforms. Capacity scale-up and liquidity are challenged when lower stock valuations restrict access to on-going investments, which, in turn, becomes a self-fulfilling prophecy as capacity and plant investments are further delayed because of the lack of access to capital.

In our research, we have heard time and time again about the importance of having solid business fundamentals. This begins by having an experienced program manager for plant start-ups. Plant construction must be carefully managed to control costs, especially with engineering procurement construction supplier contracts. Such contracts often have significant additional charges associated with change orders; thus, control over the construction process for changes need to be documented and carefully tracked to avoid major surcharges at the end of the project. It is also critical to have risk discovery and problem analysis processes established to avoid rushing into commercialization. Several executives we spoke with emphasized that rushing to commercialization to satisfy an investor was a mistake, but that it was better to take one's time and perfect the technology during the small start-up phase. Otherwise, start-up failures lead to further investment challenges with investors.

As one executive at Green Biologics pointed out, "It is critical to have an external-facing view, and be building relationships as well as educating VC's on what you think is not real. You have to build a real, viable company with a supply chain that works, and convince them that you will deliver on-time, and have lower impurities in your product, and that you are competitive. Otherwise they will just throw green out the window."

Another important criteria for success is understanding the need for major customers to seek assurances relative to business continuity. Major customers will be reluctant to work with a sole source that only has a single plant, so there is a need to establish risk-mitigation approaches that address this concern, including inventory growth, alternative plants that are coming online, and any other backup redundancies that are available.

Trend 4: Selection of the right supply chain technology partners is key, along with understanding the right market requirements for success.

The successful emerging technologies were those firms that had the right technology partners identified. In addition, it is critical that technologies target markets and develop deep market intelligence about what downstream product market customers are looking for. This is equivalent to understanding the "market pull" factors, as opposed to a technology push approach that will inevitably fail.

A good example is biosynthetic motor oil that Biosynthetic Technologies manufactured from vegetable oil. This product was demonstrated to outperform synthetic lubricants, and its performance was validated by the American Petroleum Institute. In tests, the oil ran through a 150,000 mile test and ran cleaner than petroleum motor oil, while producing higher fuel economy that amounted to a savings of three percent. The company also established several important strategic partners throughout the process, including investment bankers JP Morgan and Jeffries, and research and development groups such as Sime, Darby, Evonik, Monsanto, and BP, as well as solid manufacturing partners, Albemarle and Jacobs.

Another good example is Amyris, and its approach to product development. It produces a natural skin product that uses squalene, which prevents moisture loss, restores the skin's suppleness, and has exceptional moisturizing properties. The company provides 18% of the world's squalene supply, which is derived from natural biobased sources. The only two other sources are shark's livers, which is unsustainable and requires harvesting a large number of sharks and the other source is olives, but their supply is volatile and impurities are variable, making them difficult to use. Amyris developed a third generation squalene that is derived from sugar and is a USDA Certified Biobased Product with 100% biobased content. In developing its product, several important lessons were learned.

First, the company's leadership came to understand that there are requirements for product innovation beyond specification. For example, there were multiple other criteria that included an impurity profile and the sensorial feel of the product that couldn't be addressed in a technical formulation metric. For example, the product had to be formulated to be highly consistent using rigorous manufacturing processes. The product, which is from a renewable source, is now highly consistent, much more so than olive oil, and it performs like the shark-derived product.

The second lesson is that even when specifications are available, there are some specifications that need alignment between suppliers and customers. In this case, leadership learned that specifications do not have universal definitions. The requirement for the product to be "nearly odorless" was a specification, but had many different meanings in Japan, France, and the U.S. The team had to alter the formulation to ensure the lowest odor possible, and they established a metric where 97% of users could not detect a smell, which performed better than shark or olive sourced squalene.

Another lesson is that one should never assume that customers will be ready to buy the product as soon as it is available. In this case, it took from 6 to 24 months to test formulations and start using it in products. Leadership realized that deployments take time and an extra year was allowed for the adoption of the second product out of its lineup to ensure it is accepted. Amyris supplies 18% of the world's supply of squalene and has done so for more than three years.

Trend 5: Easy venture capital funding is no longer a reality, so long-term partnerships and alternative sources of funding are needed.

Getting access to inexpensive sugar is certainly not the only guarantee of success, but finding partners with long-term views for growth and the patience to ride out the investment is important. This may be difficult to find in the venture capital community, so partnerships with alternative providers also is important. In addition, understanding the funding landscape may require looking to government grants to support biofuels technology development, as unlocking access to inexpensive sugar will remain critical. An important insight is for companies to look for government-sponsored legislation that focuses on production credits, not just tax incentives. For example, Minnesota is beginning to introduce new biobased legislation that will provide production credits. Others include offsets to capital needed to be raised for new production sites, provided certain criteria are met; thus, encouraging investment and redirecting it into the cost of capital. This is not just a tax credit, but an actual incentive that can be used and traded on the open market.

Venture capital partners also must be selected carefully, and it must be established and understood early that growth is a long-term process. Venture capital funding in 2014 is perhaps at an all-time low, in part because of high initial expectations during 2011 and

2012 for a quick return. When the venture capital community became aware that there would be delays in product and plant outputs, disillusionment set in to some extent.

To ensure a good investor relationship outcome, it is important for innovators to recognize that a "demand pull" requirement is important, along with an ambitious vision, a focused and well-executed plan, and a top-down approach. For many typical biobased products, the key inflection point is the first commercial plant, which represents the first proof of concept and the first major milestone. As such, ensuring that the right human resources are dedicated to the millions of details that require attention to deploy a successful first plant is essential. For example, with BioAmber, a startup in 2009, half of the company was dedicated to the start-up and plant-development activities, not to research and development.

Insights for Policy

Grants and government sponsored programs will be important for the growth of the industry. The exorbitant costs of constructing commercial plants and the challenges associated with the new biobased materials and chemicals companies have significantly reduced the passion of the venture capital community for investing in this technology space. Investors are much more likely to seek companies that have complementary sources of financing. This is particularly true for smaller start-ups, such as the suppliers in Ford's supply chain. As such, government policy should seek to build out grants and debt programs that align well with current government interests in the right sectors, particularly for emerging feedstocks.

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 Forest Service land management programs. IMPLAN is now widely used to quantify the economic impacts of various industry activities and policies. The IMPLAN system is now 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 in to the economy and jobs produced (IMPLAN Group LLC 2004).[103] Data are obtained from various government sources. These include agencies and bureaus within the Departments of Agriculture, Commerce, and Labor.

The IMPLAN system's input-output model currently defines 536 unique sectors in the U.S. economy (which are North American Industry Classification System [NAICS] sectors, except in some cases where aggregates of multiple sectors are used) and uses its database 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 purchasing sectors by columns; every sector is considered to be both a processor and purchaser. Summing each row quantifies an industry's output, which includes sales to other production sectors along with those to final demand. The total outlay of inputs, which are the column sums, includes purchases from intermediate local production sectors, those from local value added, and imports (both intermediate and value added inputs) from outside the study region. A sector's economic relationships can be explained from the transactions table by the value of the commodities exchanged between the industry of interest and other sectors.

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

Leontief (1936) defined the relationship between output and final demand using Eq. 1,

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

Equation 1: Leontief's output model

where x is the column vector of industrial output, I is an identity (unit) matrix, A is the direct requirements matrix relating input to output, and y represents the final demand column vector. The term $(I - A)^{-1}$ is the total requirements matrix or the "multiplier" matrix. Each element of the matrix describes the amount needed from sector i (row) as input to produce one unit of output in sector j (column) to satisfy final demand. The output multiplier for sector j is the sum of its column elements, or sector j's total requirements from each individual sector i. Employment and value added multipliers are also derived from summing the respective column elements.

Employment in IMPLAN is represented as the number of both full and part time jobs within an industry creates to meet final demand. Value added is composed of labor income, which includes employee compensation and sole proprietor (self-employed) income, other property type income (OPI), and indirect business taxes[104]. OPI in IMPLAN includes corporate profits,

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

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 Gross Domestic product (GDP).
- Output: Output is an industry's gross sales, which includes sales to other sectors (where the output as used by that sector as input) and those 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 under study.
3. Induced effects: A change 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, the indirect and induced contributions. The Type I multiplier describes the indirect effect, which is described by dividing the direct effect into the sum of the direct and indirect effects.[105] A Type I employment multiplier of 2.00 for example, means for every employee in the industry of interest, one additional person is employed in that sector's supply chain.

Type II multipliers are defined as the sum of the direct, indirect, and induced effects divided by the direct effect (see Equation 2). 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 (see Equation 3). These multipliers indicate to what extent activity is generated in the economy due to the sectors under study. A Type SAM value added multiplier of 1.50, for example, indicates that for every $1.00 of value added produced in an industry under study, $0.50 of additional value added would be generated elsewhere in the economy by other industries.

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 to what extent the economy is influenced by the sector(s) of interest. Changes to final demand, which are generally marginal or incremental in nature, are not assumed here as in the traditional impact analysis. Based on the number of sectors contained 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

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

to households only. Output was the basis by which contributions were assessed, but it needed adjusting to discount for sales and purchases internal to the sectors so that double counting could be avoided. This required 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 found 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%. Use of this method avoided the structural changes resulting from model customization, which at the same time preserved the original relationships found in the modeled economy's transactions table.

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

Equation 2: Type I Multiplier

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

Equation 3: Type SAM Multiplier

Appendix B
Biobased Product Location Quotients by State

Table B-1 Biobased Product Quotients by State

State	Industry	Location Quotient
Alabama	Agriculture, Forestry, and Supporting Services	1.454
Alabama	Biobased Chemical Manufacturing	1.206
Alabama	Forest Products Manufacturing	2.355
Alabama	Biobased Plastics and Rubber Manufacturing	1.670
Alabama	Biobased Textiles and Apparels	2.104
Alabama	Grain and Oilseed Milling for Biobased Products	0.924
Alabama	**Biobased Products Economy**	**2.058**
Alaska	Agriculture, Forestry, and Supporting Services	0.412
Alaska	Biobased Chemical Manufacturing	0.022
Alaska	Forest Products Manufacturing	0.223
Alaska	Biobased Plastics and Rubber Manufacturing	0.094
Alaska	Biobased Textiles and Apparels	0.121
Alaska	Grain and Oilseed Milling for Biobased Products	0.000
Alaska	**Biobased Products Economy**	**0.261**
Arizona	Agriculture, Forestry, and Supporting Services	0.532
Arizona	Biobased Chemical Manufacturing	0.479
Arizona	Forest Products Manufacturing	0.521
Arizona	Biobased Plastics and Rubber Manufacturing	0.407
Arizona	Biobased Textiles and Apparels	0.329
Arizona	Grain and Oilseed Milling for Biobased Products	0.060
Arizona	**Biobased Products Economy**	**0.507**
Arkansas	Agriculture, Forestry, and Supporting Services	1.832
Arkansas	Biobased Chemical Manufacturing	0.811
Arkansas	Forest Products Manufacturing	2.288
Arkansas	Biobased Plastics and Rubber Manufacturing	1.784
Arkansas	Biobased Textiles and Apparels	0.595
Arkansas	Grain and Oilseed Milling for Biobased Products	6.041
Arkansas	**Biobased Products Economy**	**2.003**
California	Agriculture, Forestry, and Supporting Services	1.381
California	Biobased Chemical Manufacturing	0.882
California	Forest Products Manufacturing	0.612
California	Biobased Plastics and Rubber Manufacturing	0.629
California	Biobased Textiles and Apparels	1.630
California	Grain and Oilseed Milling for Biobased Products	0.648
California	**Biobased Products Economy**	**0.904**

State	Industry	Location Quotient
Colorado	Agriculture, Forestry, and Supporting Services	0.720
Colorado	Biobased Chemical Manufacturing	2.702
Colorado	Forest Products Manufacturing	0.115
Colorado	Biobased Plastics and Rubber Manufacturing	0.209
Colorado	Biobased Textiles and Apparels	0.169
Colorado	Grain and Oilseed Milling for Biobased Products	0.189
Colorado	**Biobased Products Economy**	**0.483**
Connecticut	Agriculture, Forestry, and Supporting Services	0.352
Connecticut	Biobased Chemical Manufacturing	0.633
Connecticut	Forest Products Manufacturing	0.483
Connecticut	Biobased Plastics and Rubber Manufacturing	0.735
Connecticut	Biobased Textiles and Apparels	0.589
Connecticut	Grain and Oilseed Milling for Biobased Products	0.015
Connecticut	**Biobased Products Economy**	**0.462**
Delaware	Agriculture, Forestry, and Supporting Services	0.385
Delaware	Biobased Chemical Manufacturing	2.244
Delaware	Forest Products Manufacturing	0.421
Delaware	Biobased Plastics and Rubber Manufacturing	0.840
Delaware	Biobased Textiles and Apparels	0.220
Delaware	Grain and Oilseed Milling for Biobased Products	0.061
Delaware	**Biobased Products Economy**	**0.434**
Florida	Agriculture, Forestry, and Supporting Services	0.695
Florida	Biobased Chemical Manufacturing	0.402
Florida	Forest Products Manufacturing	0.403
Florida	Biobased Plastics and Rubber Manufacturing	0.291
Florida	Biobased Textiles and Apparels	0.370
Florida	Grain and Oilseed Milling for Biobased Products	0.048
Florida	**Biobased Products Economy**	**0.479**
Georgia	Agriculture, Forestry, and Supporting Services	0.887
Georgia	Biobased Chemical Manufacturing	0.934
Georgia	Forest Products Manufacturing	1.360
Georgia	Biobased Plastics and Rubber Manufacturing	1.106
Georgia	Biobased Textiles and Apparels	4.629
Georgia	Grain and Oilseed Milling for Biobased Products	1.030
Georgia	**Biobased Products Economy**	**1.464**
Hawaii	Agriculture, Forestry, and Supporting Services	0.941

State	Industry	Location Quotient
Hawaii	Biobased Chemical Manufacturing	0.084
Hawaii	Forest Products Manufacturing	0.147
Hawaii	Biobased Plastics and Rubber Manufacturing	0.062
Hawaii	Biobased Textiles and Apparels	0.312
Hawaii	Grain and Oilseed Milling for Biobased Products	0.062
Hawaii	**Biobased Products Economy**	**0.375**
Idaho	Agriculture, Forestry, and Supporting Services	3.986
Idaho	Biobased Chemical Manufacturing	0.682
Idaho	Forest Products Manufacturing	1.864
Idaho	Biobased Plastics and Rubber Manufacturing	0.414
Idaho	Biobased Textiles and Apparels	0.326
Idaho	Grain and Oilseed Milling for Biobased Products	0.922
Idaho	**Biobased Products Economy**	**2.285**
Illinois	Agriculture, Forestry, and Supporting Services	0.472
Illinois	Biobased Chemical Manufacturing	1.463
Illinois	Forest Products Manufacturing	0.771
Illinois	Biobased Plastics and Rubber Manufacturing	1.341
Illinois	Biobased Textiles and Apparels	0.362
Illinois	Grain and Oilseed Milling for Biobased Products	2.381
Illinois	**Biobased Products Economy**	**0.680**
Indiana	Agriculture, Forestry, and Supporting Services	0.710
Indiana	Biobased Chemical Manufacturing	1.245
Indiana	Forest Products Manufacturing	1.895
Indiana	Biobased Plastics and Rubber Manufacturing	2.446
Indiana	Biobased Textiles and Apparels	0.435
Indiana	Grain and Oilseed Milling for Biobased Products	2.405
Indiana	**Biobased Products Economy**	**1.459**
Iowa	Agriculture, Forestry, and Supporting Services	2.229
Iowa	Biobased Chemical Manufacturing	1.225
Iowa	Forest Products Manufacturing	1.420
Iowa	Biobased Plastics and Rubber Manufacturing	1.493
Iowa	Biobased Textiles and Apparels	0.509
Iowa	Grain and Oilseed Milling for Biobased Products	8.680
Iowa	**Biobased Products Economy**	**1.573**
Kansas	Agriculture, Forestry, and Supporting Services	1.551
Kansas	Biobased Chemical Manufacturing	1.137

State	Industry	Location Quotient
Kansas	Forest Products Manufacturing	0.556
Kansas	Biobased Plastics and Rubber Manufacturing	1.615
Kansas	Biobased Textiles and Apparels	0.483
Kansas	Grain and Oilseed Milling for Biobased Products	2.342
Kansas	**Biobased Products Economy**	**0.851**
Kentucky	Agriculture, Forestry, and Supporting Services	1.686
Kentucky	Biobased Chemical Manufacturing	1.298
Kentucky	Forest Products Manufacturing	1.667
Kentucky	Biobased Plastics and Rubber Manufacturing	2.130
Kentucky	Biobased Textiles and Apparels	0.703
Kentucky	Grain and Oilseed Milling for Biobased Products	0.622
Kentucky	**Biobased Products Economy**	**1.601**
Louisiana	Agriculture, Forestry, and Supporting Services	1.010
Louisiana	Biobased Chemical Manufacturing	2.052
Louisiana	Forest Products Manufacturing	0.947
Louisiana	Biobased Plastics and Rubber Manufacturing	0.353
Louisiana	Biobased Textiles and Apparels	0.223
Louisiana	Grain and Oilseed Milling for Biobased Products	0.861
Louisiana	**Biobased Products Economy**	**0.919**
Maine	Agriculture, Forestry, and Supporting Services	2.468
Maine	Biobased Chemical Manufacturing	0.467
Maine	Forest Products Manufacturing	2.659
Maine	Biobased Plastics and Rubber Manufacturing	0.790
Maine	Biobased Textiles and Apparels	1.224
Maine	Grain and Oilseed Milling for Biobased Products	0.267
Maine	**Biobased Products Economy**	**2.430**
Maryland	Agriculture, Forestry, and Supporting Services	0.274
Maryland	Biobased Chemical Manufacturing	0.755
Maryland	Forest Products Manufacturing	0.464
Maryland	Biobased Plastics and Rubber Manufacturing	0.439
Maryland	Biobased Textiles and Apparels	0.412
Maryland	Grain and Oilseed Milling for Biobased Products	0.419
Maryland	**Biobased Products Economy**	**0.413**
Massachusetts	Agriculture, Forestry, and Supporting Services	0.208
Massachusetts	Biobased Chemical Manufacturing	0.780
Massachusetts	Forest Products Manufacturing	0.551

State	Industry	Location Quotient
Massachusetts	Biobased Plastics and Rubber Manufacturing	0.780
Massachusetts	Biobased Textiles and Apparels	0.949
Massachusetts	Grain and Oilseed Milling for Biobased Products	0.256
Massachusetts	**Biobased Products Economy**	**0.494**
Michigan	Agriculture, Forestry, and Supporting Services	0.990
Michigan	Biobased Chemical Manufacturing	1.263
Michigan	Forest Products Manufacturing	1.263
Michigan	Biobased Plastics and Rubber Manufacturing	2.144
Michigan	Biobased Textiles and Apparels	0.273
Michigan	Grain and Oilseed Milling for Biobased Products	1.380
Michigan	**Biobased Products Economy**	**1.129**
Minnesota	Agriculture, Forestry, and Supporting Services	1.297
Minnesota	Biobased Chemical Manufacturing	0.540
Minnesota	Forest Products Manufacturing	1.245
Minnesota	Biobased Plastics and Rubber Manufacturing	0.884
Minnesota	Biobased Textiles and Apparels	0.437
Minnesota	Grain and Oilseed Milling for Biobased Products	2.425
Minnesota	**Biobased Products Economy**	**1.181**
Mississippi	Agriculture, Forestry, and Supporting Services	2.184
Mississippi	Biobased Chemical Manufacturing	0.956
Mississippi	Forest Products Manufacturing	3.528
Mississippi	Biobased Plastics and Rubber Manufacturing	1.145
Mississippi	Biobased Textiles and Apparels	1.464
Mississippi	Grain and Oilseed Milling for Biobased Products	0.799
Mississippi	**Biobased Products Economy**	**2.920**
Missouri	Agriculture, Forestry, and Supporting Services	0.917
Missouri	Biobased Chemical Manufacturing	1.176
Missouri	Forest Products Manufacturing	0.947
Missouri	Biobased Plastics and Rubber Manufacturing	0.998
Missouri	Biobased Textiles and Apparels	0.496
Missouri	Grain and Oilseed Milling for Biobased Products	2.357
Missouri	**Biobased Products Economy**	**0.910**
Montana	Agriculture, Forestry, and Supporting Services	2.829
Montana	Biobased Chemical Manufacturing	0.198
Montana	Forest Products Manufacturing	1.067
Montana	Biobased Plastics and Rubber Manufacturing	0.120

State	Industry	Location Quotient
Montana	Biobased Textiles and Apparels	0.246
Montana	Grain and Oilseed Milling for Biobased Products	1.122
Montana	**Biobased Products Economy**	**1.457**
Nebraska	Agriculture, Forestry, and Supporting Services	2.214
Nebraska	Biobased Chemical Manufacturing	0.827
Nebraska	Forest Products Manufacturing	0.659
Nebraska	Biobased Plastics and Rubber Manufacturing	1.043
Nebraska	Biobased Textiles and Apparels	0.237
Nebraska	Grain and Oilseed Milling for Biobased Products	4.983
Nebraska	**Biobased Products Economy**	**1.064**
Nevada	Agriculture, Forestry, and Supporting Services	0.257
Nevada	Biobased Chemical Manufacturing	0.356
Nevada	Forest Products Manufacturing	0.303
Nevada	Biobased Plastics and Rubber Manufacturing	0.483
Nevada	Biobased Textiles and Apparels	0.197
Nevada	Grain and Oilseed Milling for Biobased Products	0.384
Nevada	**Biobased Products Economy**	**0.287**
New Hampshire	Agriculture, Forestry, and Supporting Services	0.612
New Hampshire	Biobased Chemical Manufacturing	0.626
New Hampshire	Forest Products Manufacturing	0.871
New Hampshire	Biobased Plastics and Rubber Manufacturing	1.382
New Hampshire	Biobased Textiles and Apparels	0.214
New Hampshire	Grain and Oilseed Milling for Biobased Products	0.000
New Hampshire	**Biobased Products Economy**	**0.755**
New Jersey	Agriculture, Forestry, and Supporting Services	0.282
New Jersey	Biobased Chemical Manufacturing	1.670
New Jersey	Forest Products Manufacturing	0.492
New Jersey	Biobased Plastics and Rubber Manufacturing	0.775
New Jersey	Biobased Textiles and Apparels	0.773
New Jersey	Grain and Oilseed Milling for Biobased Products	0.486
New Jersey	**Biobased Products Economy**	**0.481**
New Mexico	Agriculture, Forestry, and Supporting Services	1.346
New Mexico	Biobased Chemical Manufacturing	0.472
New Mexico	Forest Products Manufacturing	0.392
New Mexico	Biobased Plastics and Rubber Manufacturing	0.166
New Mexico	Biobased Textiles and Apparels	0.101

State	Industry	Location Quotient
New Mexico	Grain and Oilseed Milling for Biobased Products	1.257
New Mexico	**Biobased Products Economy**	**0.629**
New York	Agriculture, Forestry, and Supporting Services	0.326
New York	Biobased Chemical Manufacturing	0.840
New York	Forest Products Manufacturing	0.547
New York	Biobased Plastics and Rubber Manufacturing	0.474
New York	Biobased Textiles and Apparels	0.894
New York	Grain and Oilseed Milling for Biobased Products	0.306
New York	**Biobased Products Economy**	**0.516**
North Carolina	Agriculture, Forestry, and Supporting Services	1.074
North Carolina	Biobased Chemical Manufacturing	1.747
North Carolina	Forest Products Manufacturing	2.166
North Carolina	Biobased Plastics and Rubber Manufacturing	1.544
North Carolina	Biobased Textiles and Apparels	4.634
North Carolina	Grain and Oilseed Milling for Biobased Products	0.746
North Carolina	**Biobased Products Economy**	**2.034**
North Dakota	Agriculture, Forestry, and Supporting Services	2.894
North Dakota	Biobased Chemical Manufacturing	0.077
North Dakota	Forest Products Manufacturing	0.848
North Dakota	Biobased Plastics and Rubber Manufacturing	0.611
North Dakota	Biobased Textiles and Apparels	0.495
North Dakota	Grain and Oilseed Milling for Biobased Products	3.938
North Dakota	**Biobased Products Economy**	**1.355**
Ohio	Agriculture, Forestry, and Supporting Services	0.549
Ohio	Biobased Chemical Manufacturing	1.395
Ohio	Forest Products Manufacturing	1.014
Ohio	Biobased Plastics and Rubber Manufacturing	2.233
Ohio	Biobased Textiles and Apparels	0.378
Ohio	Grain and Oilseed Milling for Biobased Products	1.158
Ohio	**Biobased Products Economy**	**0.866**
Oklahoma	Agriculture, Forestry, and Supporting Services	1.452
Oklahoma	Biobased Chemical Manufacturing	0.477
Oklahoma	Forest Products Manufacturing	0.546
Oklahoma	Biobased Plastics and Rubber Manufacturing	1.230
Oklahoma	Biobased Textiles and Apparels	0.224
Oklahoma	Grain and Oilseed Milling for Biobased Products	0.887

State	Industry	Location Quotient
Oklahoma	**Biobased Products Economy**	**0.781**
Oregon	Agriculture, Forestry, and Supporting Services	3.679
Oregon	Biobased Chemical Manufacturing	0.435
Oregon	Forest Products Manufacturing	2.274
Oregon	Biobased Plastics and Rubber Manufacturing	0.581
Oregon	Biobased Textiles and Apparels	0.509
Oregon	Grain and Oilseed Milling for Biobased Products	0.655
Oregon	**Biobased Products Economy**	**2.466**
Pennsylvania	Agriculture, Forestry, and Supporting Services	0.515
Pennsylvania	Biobased Chemical Manufacturing	0.988
Pennsylvania	Forest Products Manufacturing	1.248
Pennsylvania	Biobased Plastics and Rubber Manufacturing	1.147
Pennsylvania	Biobased Textiles and Apparels	0.843
Pennsylvania	Grain and Oilseed Milling for Biobased Products	0.750
Pennsylvania	**Biobased Products Economy**	**1.011**
Rhode Island	Agriculture, Forestry, and Supporting Services	0.180
Rhode Island	Biobased Chemical Manufacturing	1.245
Rhode Island	Forest Products Manufacturing	0.755
Rhode Island	Biobased Plastics and Rubber Manufacturing	0.972
Rhode Island	Biobased Textiles and Apparels	1.691
Rhode Island	Grain and Oilseed Milling for Biobased Products	0.055
Rhode Island	**Biobased Products Economy**	**0.680**
South Carolina	Agriculture, Forestry, and Supporting Services	1.029
South Carolina	Biobased Chemical Manufacturing	2.056
South Carolina	Forest Products Manufacturing	1.445
South Carolina	Biobased Plastics and Rubber Manufacturing	2.079
South Carolina	Biobased Textiles and Apparels	4.261
South Carolina	Grain and Oilseed Milling for Biobased Products	0.239
South Carolina	**Biobased Products Economy**	**1.563**
South Dakota	Agriculture, Forestry, and Supporting Services	2.859
South Dakota	Biobased Chemical Manufacturing	0.550
South Dakota	Forest Products Manufacturing	1.792
South Dakota	Biobased Plastics and Rubber Manufacturing	0.740
South Dakota	Biobased Textiles and Apparels	1.247
South Dakota	Grain and Oilseed Milling for Biobased Products	0.715
South Dakota	**Biobased Products Economy**	**2.004**

State	Industry	Location Quotient
Tennessee	Agriculture, Forestry, and Supporting Services	0.756
Tennessee	Biobased Chemical Manufacturing	1.811
Tennessee	Forest Products Manufacturing	1.464
Tennessee	Biobased Plastics and Rubber Manufacturing	1.600
Tennessee	Biobased Textiles and Apparels	1.388
Tennessee	Grain and Oilseed Milling for Biobased Products	1.691
Tennessee	**Biobased Products Economy**	**1.273**
Texas	Agriculture, Forestry, and Supporting Services	0.676
Texas	Biobased Chemical Manufacturing	1.146
Texas	Forest Products Manufacturing	0.671
Texas	Biobased Plastics and Rubber Manufacturing	0.678
Texas	Biobased Textiles and Apparels	0.448
Texas	Grain and Oilseed Milling for Biobased Products	0.468
Texas	**Biobased Products Economy**	**0.664**
Utah	Agriculture, Forestry, and Supporting Services	0.631
Utah	Biobased Chemical Manufacturing	1.056
Utah	Forest Products Manufacturing	1.083
Utah	Biobased Plastics and Rubber Manufacturing	0.698
Utah	Biobased Textiles and Apparels	0.416
Utah	Grain and Oilseed Milling for Biobased Products	1.055
Utah	**Biobased Products Economy**	**0.903**
Vermont	Agriculture, Forestry, and Supporting Services	1.439
Vermont	Biobased Chemical Manufacturing	0.636
Vermont	Forest Products Manufacturing	1.634
Vermont	Biobased Plastics and Rubber Manufacturing	0.671
Vermont	Biobased Textiles and Apparels	0.522
Vermont	Grain and Oilseed Milling for Biobased Products	0.082
Vermont	**Biobased Products Economy**	**1.463**
Virginia	Agriculture, Forestry, and Supporting Services	0.758
Virginia	Biobased Chemical Manufacturing	0.641
Virginia	Forest Products Manufacturing	0.986
Virginia	Biobased Plastics and Rubber Manufacturing	0.914
Virginia	Biobased Textiles and Apparels	1.356
Virginia	Grain and Oilseed Milling for Biobased Products	0.282
Virginia	**Biobased Products Economy**	**0.944**
Washington	Agriculture, Forestry, and Supporting Services	4.074

State	Industry	Location Quotient
Washington	Biobased Chemical Manufacturing	0.395
Washington	Forest Products Manufacturing	1.157
Washington	Biobased Plastics and Rubber Manufacturing	0.650
Washington	Biobased Textiles and Apparels	0.413
Washington	Grain and Oilseed Milling for Biobased Products	0.785
Washington	**Biobased Products Economy**	**1.878**
West Virginia	Agriculture, Forestry, and Supporting Services	0.944
West Virginia	Biobased Chemical Manufacturing	2.360
West Virginia	Forest Products Manufacturing	1.185
West Virginia	Biobased Plastics and Rubber Manufacturing	0.869
West Virginia	Biobased Textiles and Apparels	0.137
West Virginia	Grain and Oilseed Milling for Biobased Products	0.000
West Virginia	**Biobased Products Economy**	**1.054**
Wisconsin	Agriculture, Forestry, and Supporting Services	1.283
Wisconsin	Biobased Chemical Manufacturing	0.859
Wisconsin	Forest Products Manufacturing	2.834
Wisconsin	Biobased Plastics and Rubber Manufacturing	1.953
Wisconsin	Biobased Textiles and Apparels	0.482
Wisconsin	Grain and Oilseed Milling for Biobased Products	1.382
Wisconsin	**Biobased Products Economy**	**2.183**
Wyoming	Agriculture, Forestry, and Supporting Services	1.819
Wyoming	Biobased Chemical Manufacturing	1.701
Wyoming	Forest Products Manufacturing	0.277
Wyoming	Biobased Plastics and Rubber Manufacturing	0.096
Wyoming	Biobased Textiles and Apparels	0.333
Wyoming	Grain and Oilseed Milling for Biobased Products	0.100
Wyoming	**Biobased Products Economy**	**0.725**

Appendix C
Biorefineries in the United States

Table C-1 Biorefineries in the United States

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
1	ABE South Dakota - Aberdeen	Aberdeen, SD	Corn	53	53	
2	ABE South Dakota - Huron	Huron, SD	Corn	32	32	
3	Abengoa Bioenergy Corp.	Madison, IL	Corn	90	90	
4	Abengoa Bioenergy Corp.	Mt. Vernon, IN	Corn	90	90	
5	Abengoa Bioenergy Corp.	Colwich, KS	Corn/ Sorghum	25	0	
6	Abengoa Bioenergy Corp.	Ravenna, NE	Corn	88	88	
7	Abengoa Bioenergy Corp.	Road O York, NE	Corn	55	55	
8	Abengoa Bioenergy Corp.	Portales, NM	Corn	30	0	
9	Abengoa Bioenergy Corp.	Hugoton, KS	Cellulosic Biomass	25	25	
10	Absolute Energy, LLC	St. Ansgar, IA	Corn	115	115	
11	ACE Ethanol, LLC	Stanley, WI	Corn	41	41	
12	Adkins Energy, LLC*	Lena, IL	Corn	45	45	
13	Aemetis	Keyes, CA	Corn/ Sorghum	55	55	
14	Al-Corn Clean Fuel	Claremont, MN	Corn	45	45	
15	Archer Daniels Midland	Cedar Rapids, IA	Corn	See total in row 22	See total in row 22	
16	Archer Daniels Midland	Clinton, IA	Corn	See total in row 22	See total in row 22	
17	Archer Daniels Midland	Decatur, IL	Corn	See total in row 22	See total in row 22	
18	Archer Daniels Midland	Peoria, IL	Corn	See total in row 22	See total in row 22	
19	Archer Daniels Midland	Marshall, MN	Corn	See total in row 22	See total in row 22	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
20	Archer Daniels Midland	Columbus, NE	Corn	See total in row 22	See total in row 22	
21	Archer Daniels Midland	Cedar Rapids, IA	Corn	See total in row 22	See total in row 22	
22	Archer Daniels Midland	Columbus, NE	Corn	See total in row 22	See total in row 22	
23	Archer Daniels Midland (total)	-	-	1762	1762	0
24	Arkalon Energy, LLC	Liberal, KS	Corn	110	110	
25	Aventine Renewable Energy, LLC	Pekin, IL	Corn	100	100	
26	Aventine Renewable Energy, LLC	Aurora West, NE	Corn	110	110	
27	Aventine Renewable Energy, LLC	Canton, IL	Corn	38		
28	Aventine Renewable Energy, LLC	Aurora East, NE	Corn	45	45	
29	Aventine Renewable Energy, LLC	Pekin, IL	Corn	57	57	
30	Badger State Ethanol, LLC	Monroe, WI	Corn	50	50	
31	Big River Resources Boyceville LLC	Boyceville, WI	Corn	40	40	
32	Big River Resources Galva, LLC	Galva, IL	Corn	100	100	
33	Big River Resources, LLC	West Burlington, IA	Corn	100	100	
34	Big River United Energy	Dyersville, IA	Corn	110	110	
35	Blue Flint Ethanol	Underwood,	Corn	50	50	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
		ND				
36	Bonanza Energy, LLC	Garden City, KS	Corn/ Sorghum	55	55	
37	BP Biofuels North America	Jennings, LA	Sugarcane Bagasse	1	0	
38	Bridgeport Ethanol	Bridgeport, NE	Corn	54	54	
39	Buffalo Lake Advanced Biofuels	Buffalo Lake, MN	Corn	18	0	
40	Bushmills Ethanol, Inc.	Atwater, MN	Corn	50	50	
41	Calgren Renewable Fuels, LLC	Pixley, CA	Corn	60	60	
42	Carbon Green Bioenergy	Lake Odessa, MI	Corn	55	55	
43	Cardinal Ethanol	Union City, IN	Corn	100	100	
44	Cargill, Inc.	Eddyville, IA	Corn	35	35	
45	Cargill, Inc.	Blair, NE	Corn	195	195	
46	Cargill, Inc.	Ft. Dodge, IA	Corn	115	115	
47	Center Ethanol Company	Sauget, IL	Corn	54	54	
48	Central Indiana Ethanol, LLC	Marion, IN	Corn	50	50	
49	Central MN Renewables, LLC	Little Falls, MN	Corn	22	22	
50	Chief Ethanol	Hastings, NE	Corn	62	62	
51	Chippewa Valley Ethanol Co.	Benson, MN	Corn	45	45	
52	Columbia Pacific Biorefinery	Clatskanie, OR	Corn	108		
53	Commonwealth Agri-Energy, LLC	Hopkinsville, KY	Corn	33	33	
54	Corn Plus, LLP	Winnebago, MN	Corn	49	49	
55	Corn, LP	Goldfield, IA	Corn	60	60	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
56	Cornhusker Energy Lexington, LLC	Lexington, NE	Corn	40	40	
57	Dakota Ethanol, LLC	Wentworth, SD	Corn	50	50	
58	Dakota Spirit AgEnergy LLC	Spiritwood, ND	Corn			65
59	DENCO II	Morris, MN	Corn	24	24	
60	Diamond Ethanol	Levelland, TX	Corn	40	40	
61	Didion Ethanol	Cambria, WI	Corn	40	40	
62	Dubay Biofuels Greenwood	Greenwood, WI	Cheese Whey			5
63	DuPont	Nevada, IA	Cellulosic Biomass	30		30
64	E Energy Adams, LLC	Adams, NE	Corn	50	50	
65	East Kansas Agri-Energy, LLC	Garnett, KS	Corn	42	42	
66	Ergon Ethanol	Vicksburg, MS	Corn	54	0	
67	ESE Alcohol Inc.	Leoti, KS	Seed Corn	2	2	
68	Fiberight, LLC	Blairstown, IA	Cellulose	5	0	
69	Flint Hills Resources LP	Fairmont, NE	Corn	110	110	
70	Flint Hills Resources LP	Arthur, IA	Corn	110	110	
71	Flint Hills Resources LP	Fairbank, IA	Corn	115	115	
72	Flint Hills Resources LP	Iowa Falls, IA	Corn	105	105	
73	Flint Hills Resources LP	Menlo, IA	Corn	110	110	
74	Flint Hills Resources LP	Shell Rock, IA	Corn	110	110	
75	Flint Hills Resources LP	Camilla, GA	Corn	100	100	
76	Fox River Valley	Oshkosh, WI	Corn	50	50	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
	Ethanol					
77	Front Range Energy, LLC	Windsor, CO	Corn	40	40	
78	Gevo	Luverne, MN	Corn	21	21	
79	Glacial Lakes Energy, LLC - Mina	Mina, SD	Corn	107	107	
80	Glacial Lakes Energy, LLC	Watertown, SD	Corn	100	100	
81	Golden Cheese Company of California	Corona, CA	Cheese Whey	5	0	
82	Golden Grain Energy, LLC	Mason City, IA	Corn	115	115	
83	Golden Triangle Energy, LLC	Craig, MO	Corn	20	5	
84	Grain Processing Corp.	Muscatine, IA	Corn	20	20	
85	Grain Processing Corp.	Washington, IN	Corn	20	20	
86	Granite Falls Energy, LLC	Granite Falls, MN	Corn	52	52	
87	Green Plains Renewable Energy	Fairmont, MN	Corn	115	115	
88	Green Plains Renewable Energy	Wood River, NE	Corn	115	115	
89	Green Plains Renewable Energy	Atkinson, NE	Corn	44	44	
90	Green Plains Renewable Energy	Fergus Falls, MN	Corn	60	60	
91	Green Plains Renewable Energy	Lakota, IA	Corn	100	100	
92	Green Plains Renewable Energy	Riga, MI	Corn	60	60	
93	Green Plains Renewable Energy	Shenan-doah, IA	Corn	55	55	
94	Green Plains	Superior, IA	Corn	60	60	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
	Renewable Energy					
95	Green Plains Renewable Energy	Bluffton, IN	Corn	120	120	
96	Green Plains Renewable Energy	Central City, NE	Corn	100	100	
97	Green Plains Renewable Energy	Ord, NE	Corn	55	55	
98	Green Plains Renewable Energy	Obion, TN	Corn	120	120	
99	Guardian Energy	Janesville, MN	Corn	110	110	
100	Guardian Hankinson, LLC	Hankinson, ND	Corn	132	132	
101	Guardian Lima, LLC	Lima, OH	Corn	54	54	
102	Heartland Corn Products	Winthrop, MN	Corn	100	100	
103	Heron Lake BioEnergy, LLC	Heron Lake, MN	Corn	50	50	
104	Highwater Ethanol LLC	Lamberton, MN	Corn	55	55	
105	Homeland Energy	New Hampton, IA	Corn	100	100	
106	Husker Ag, LLC	Plainview, NE	Corn	75	75	
107	Illinois Corn Processing	Pekin, IL	Corn	90	90	
108	Illinois River Energy, LLC	Rochelle, IL	Corn	100	100	
109	Iroquois Bio-Energy Company, LLC	Rensselaer, IN	Corn	40	40	
110	KAAPA Ethanol, LLC	Minden, NE	Corn	59	59	
111	Kansas Ethanol, LLC	Lyons, KS	Corn	60	60	
112	Land O' Lakes	Melrose, MN	Cheese Whey	3	3	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
113	Lifeline Foods, LLC	St. Joseph, MO	Corn	50	50	
114	Lincolnland Agri-Energy, LLC	Palestine, IL	Corn	48	48	
115	Lincolnway Energy, LLC	Nevada, IA	Corn	55	55	
116	Little Sioux Corn Processors, LP	Marcus, IA	Corn	92	92	
117	Louis Dreyfus Commodities	Grand Junction, IA	Corn	100	100	
118	Louis Dreyfus Commodities	Norfolk, NE	Corn	45	45	
119	Marquis Energy - Wisconsin, LLC	Necedah, WI	Corn	60	60	
120	Marquis Energy, LLC	Hennepin, IL	Corn	130	130	
121	Marysville Ethanol, LLC	Marysville, MI	Corn	50	50	
122	Merrick and Company	Aurora, CO	Waste Beer	3	3	
123	Mid America Agri Products/Wheatland	Madrid, NE	Corn	44	44	
124	Mid-Missouri Energy, Inc.	Malta Bend, MO	Corn	50	50	
125	Midwest Renewable Energy, LLC	Sutherland, NE	Corn	28	0	
126	Murphy Oil	Hereford, TX	Corn/ Sorghum	105	105	
127	Nebraska Corn Processing, LLC	Cambridge, NE	Corn	45	45	
128	Nesika Energy, LLC	Scandia, KS	Corn	10	10	
129	Noble Americas South Bend Ethanol	South Bend, IN	Corn	102	0	
130	NuGen Energy	Marion, SD	Corn	110	110	
131	One Earth Energy	Gibson City, IL	Corn	100	100	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
132	Pacific Ethanol	Madera, CA	Corn/ Sorghum	40		
133	Pacific Ethanol	Stockton, CA	Corn/ Sorghum	60	60	
134	Pacific Ethanol	Burley, ID	Corn	50	50	
135	Pacific Ethanol	Boardman, OR	Corn	40	40	
136	Parallel Products	Rancho Cucamonga, CA		See total in row 138	See total in row 138	
137	Parallel Products	Louisville, KY	Beverage Waste	See total in row 138	See total in row 138	
138	Parallel Products (total)			5	5	
139	Patriot Renewable Fuels, LLC	Annawan, IL	Corn	130	130	
140	Penford Products	Cedar Rapids, IA	Corn	45	45	
141	Pennsylvania Grain Processing LLC	Clearfield, PA	Corn	110	110	
142	Pinal Energy, LLC	Maricopa, AZ	Corn	50	50	
143	Pine Lake Corn Processors, LLC	Steamboat Rock, IA	Corn	30	30	
144	Plymouth Ethanol, LLC	Merrill, IA	Corn	50	50	
145	POET Biorefining - Alexandria	Alexandria, IN	Corn	68	68	
146	POET Biorefining - Ashton	Ashton, IA	Corn	56	56	
147	POET Biorefining - Big Stone	Big Stone City, SD	Corn	79	79	
148	POET Biorefining - Bingham Lake	Bingham Lake, MN		35	35	
149	POET Biorefining - Caro	Caro, MI	Corn	50	50	0
150	POET Biorefining - Chancellor	Chancellor, SD	Corn	110	110	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
151	POET Biorefining - Cloverdale	Cloverdale, IN	Corn	92	92	
152	POET Biorefining - Coon Rapids	Coon Rapids, IA	Corn	54	54	
153	POET Biorefining - Corning	Corning, IA	Corn	65	65	
154	POET Biorefining - Emmetsburg	Emmets-burg, IA	Corn	55	55	
155	POET Biorefining - Fostoria	Fostoria, OH	Corn	68	68	
156	POET Biorefining - Glenville	Albert Lea, MN	Corn	42	42	
157	POET Biorefining - Gowrie	Gowrie, IA	Corn	69	69	
158	POET Biorefining - Hanlontown	Hanlon-town, IA	Corn	56	56	
159	POET Biorefining - Hudson	Hudson, SD	Corn	56	56	
160	POET Biorefining - Jewell	Jewell, IA	Corn	69	69	
161	POET Biorefining - Laddonia	Laddonia, MO	Corn	50	50	
162	POET Biorefining - Lake Crystal	Lake Crystal, MN	Corn	56	56	
163	POET Biorefining - Leipsic	Leipsic, OH	Corn	68	68	
164	POET Biorefining - Macon	Macon, MO	Corn	46	46	
165	POET Biorefining - Marion	Marion, OH	Corn	68	68	
166	POET Biorefining - Mitchell	Mitchell, SD	Corn	68	68	
167	POET Biorefining - North Manchester	North Manchester, IN	Corn	68	68	
168	POET Biorefining - Portland	Portland, IN	Corn	68	68	
169	POET Biorefining -	Preston, MN	Corn	46	46	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
	Preston					
170	POET Biorefining - Scotland	Scotland, SD	Corn	11	11	
171	POET Biorefining- Groton	Groton, SD	Corn	53	53	
172	Prairie Horizon Agri-Energy, LLC	Phillipsburg, KS	Corn	40	40	
173	Pratt Energy	Pratt, KS	Corn	55	55	
174	Project Liberty	Emmetsburg, IA	Cellulosic Biomass	20	20	
175	Quad-County Corn Processors	Galva, IA	Corn/ Cellulosic Biomass	37	37	
176	Red River Energy, LLC*	Rosholt, SD	Corn	25	25	
177	Red Trail Energy, LLC	Richardton, ND	Corn	50	50	
178	Redfield Energy, LLC	Redfield, SD	Corn	50	50	
179	Reeve Agri-Energy	Garden City, KS	Corn/ Sorghum	12	12	
180	Renova Energy	Torrington, WY	Corn	10	10	
181	Show Me Ethanol	Carrollton, MO	Corn	55	55	
182	Siouxland Energy & Livestock Coop*	Sioux Center, IA	Corn	60	60	
183	Siouxland Ethanol, LLC	Jackson, NE	Corn	50	50	
184	Southwest Iowa Renewable Energy, LLC	Council Bluffs, IA	Corn	110	110	
185	Spectrum Business Ventures Inc.	Mead, NE	Corn	25		
186	Sterling Ethanol, LLC	Sterling, CO	Corn	42	42	
187	Summit Natural Energy	Cornelius, OR	Waste Sugars/	1	1	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
			Starches			
188	Sunoco	Volney, NY	Corn	114	114	
189	Tate & Lyle	Loudon, TN	Corn	105	105	0
190	Tharaldson Ethanol	Casselton, ND	Corn/ Sorghum	150	150	
191	The Andersons Albion Ethanol LLC	Albion, MI	Corn	55	55	
192	The Andersons Clymers Ethanol LLC	Clymers, IN	Corn	110	110	
193	The Andersons Denison Ethanol LLC	Denison, IA	Corn	55	55	
194	The Andersons Marathon Ethanol LLC	Greenville, OH	Corn	110	110	
195	Three Rivers Energy	Coshocton, OH	Corn	50	50	
196	Trenton Agri Products LLC	Trenton, NE	Corn	40	40	
197	United Ethanol	Milton, WI	Corn	52	52	
198	United WI Grain Producers, LLC	Friesland, WI	Corn	53	53	
199	Valero Renewable Fuels	Albert City, IA	Corn	110	110	
200	Valero Renewable Fuels	Charles City, IA	Corn	110	110	
201	Valero Renewable Fuels	Ft. Dodge, IA	Corn	110	110	
202	Valero Renewable Fuels	Hartley, IA	Corn	110	110	
203	Valero Renewable Fuels	Welcome, MN	Corn	110	110	
204	Valero Renewable Fuels	Albion, NE	Corn	110	110	
205	Valero Renewable Fuels	Aurora, SD	Corn	120	120	

	Company	Location	Feedstock	Nameplate Capacity (mgy)	Operating Production (mgy)	Under Construction/Expansion Capacity (mgy)
206	Valero Renewable Fuels	North Linden, IN	Corn	110	110	
207	Valero Renewable Fuels	Blooming-burg, OH	Corn	110	110	
208	Valero Renewable Fuels	Jefferson Junction, WI	Corn	130	130	
209	Valero Renewable Fuels	Mount Vernon, IN	Corn	110	110	
210	Vireol Bio-Energy LLC	Hopewell, VA	Corn/Barley	65	65	
211	Western New York Energy LLC	Shelby, NY		50	50	
212	Western Plains Energy, LLC*	Campus, KS	Corn	45	45	
213	White Energy	Russell, KS	Sorghum/ Wheat starch	48	48	
214	White Energy	Hereford, TX	Corn/ Sorghum	100	100	
215	White Energy	Plainview, TX	Corn	110	110	
216	Wind Gap Farms	Baconton, GA	Brewery Waste	1	1	
217	Yuma Ethanol	Yuma, CO	Corn	40	40	
	TOTALS			**15,069 mgy nameplate capacity**	**14,575 mgy operating production**	**100 mgy for under construction/expanding refineries**

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

Appendix D
Products Registered with the BioPreferred® Program by Category - 2015

Table D-1 Products Registered with the BioPreferred® Program by Category - 2015

Number of Products	Category
35	2-Cycle Engine Oils
61	Adhesive and Mastic Removers
29	Adhesives
63	Agricultural Spray Adjuvants
133	Air Fresheners and Deodorizers
37	Aircraft and Boat Cleaners - Aircraft Cleaners
37	Aircraft and Boat Cleaners - Boat Cleaners
10	Allergy and Sinus Relievers
29	Animal Bedding
336	Animal Cleaning Products
59	Animal Habitat Care Products
36	Animal Medical Care Products
72	Animal Odor Control and Deodorant
129	Animal Repellents
52	Animal Skin, Hair, and Insect Care Products
14	Anti-Slip Products
2	Anti-Spatter Products
333	Aromatherapy
98	Art Supplies
38	Asphalt and Tar Removers
7	Asphalt Restorers
5	Asphalt Roofing Materials: Low Slope
1	Automotive Tires
1	Barrier Fluid
1177	Bath Products
261	Bathroom and Spa Cleaners
167	Bedding, Bed Linens, and Towels
15	Biodegradable Foams
183	Bioremediation Materials
15	Blast Media
62	Body Powders
530	Candles and Wax Melts
86	Car Cleaners
114	Carpet and Upholstery Cleaners - General Purpose

Number of Products	Category
122	Carpet and Upholstery Cleaners - Spot Removers
102	Carpets
117	Chain and Cable Lubricants
316	Clothing
51	Composite Panels - Acoustical
35	Composite Panels - Countertops and Solid Surface Products
69	Composite Panels - Interior Panels
22	Composite Panels - Plastic Lumber
27	Composite Panels - Structural Interior Panels
18	Composite Panels - Structural Wall Panels
31	Compost Activators and Accelerators
79	Concrete and Asphalt Cleaners
61	Concrete and Asphalt Release Fluids
4	Concrete Curing Agents
2	Concrete Repair Patch
69	Corrosion Preventatives
234	Cosmetics
92	Cuts, Burns, and Abrasions Ointments
15	De-Icers - Specialty
86	Deodorants
14	Dethatchers
73	Diesel Fuel Additives
145	Dishwashing Products
4	Disinfectants
416	Disposable Containers
510	Disposable Cutlery
628	Disposable Tableware
19	Durable Cutlery
44	Durable Tableware
34	Dust Suppressants
10	Electronic Components Cleaners
64	Engine Crankcase Oil
248	Erosion Control Materials
2	Expanded Polystyrene (EPS) Foam Recycling Products
45	Exterior Paints and Coatings

Number of Products	Category
2	Fabric Stain Preventers and Protectors
1576	Facial Care Products
536	Fertilizers
107	Films - Non-Durable
44	Films - Semi-Durable
3	Filters
121	Fingernail/Cuticle Products
7	Fire Retardants
12	Fire Starters, Logs, or Pellets
45	Firearm Cleaner
41	Firearm Lubricants
163	Floor Cleaners and Protectors
360	Floor Coverings (Non-Carpet)
11	Floor Finishes and Waxes
14	Floor Strippers
6	Fluid-Filled Transformers - Synthetic Ester-Based
6	Fluid-Filled Transformers - Vegetable Oil-Based
35	Foliar Sprays
35	Food Cleaners
93	Foot Care Products
24	Forming Lubricants
27	Fuel Conditioners
46	Furniture Cleaners and Protectors
111	Gasoline Fuel Additives
107	Gear Lubricants
29	General Purpose De-Icers
281	General Purpose Household Cleaners
184	Glass Cleaners
319	Graffiti and Grease Removers
20	Greases
24	Greases - Food Grade
49	Greases - Multipurpose
15	Greases - Rail Track
14	Greases - Truck
7	Greases - Wheel Bearing and Chassis Greases

Number of Products	Category
16	Hair Care Products - Conditioners
473	Hair Care Products - Shampoos
183	Hair Removal - Depilatory Products
120	Hair Styling Products
432	Hand Cleaners and Sanitizers - Hand Cleaners
119	Hand Cleaners and Sanitizers - Hand Sanitizers
11	Heat Generating Products
2	Heat Transfer Fluid - Additive
60	Heat Transfer Fluids
228	Hydraulic Fluids - Mobile Equipment
244	Hydraulic Fluids - Stationary Equipment
377	Industrial Cleaners
12	Industrial Enamel Coatings
31	Ink Removers and Cleaners
21	Inks - News
65	Inks - Printer Toner (Greater Than 25 Pages Per Minute)
42	Inks - Printer Toner (Less Than 25 Pages Per Minute)
19	Inks - Sheetfed (Black)
41	Inks - Sheetfed (Color)
51	Inks - Specialty
8	Insulation - Other
47	Interior Paints and Coatings - Latex and Waterborne Alkyd
32	Interior Paints and Coatings - Oil-based and Solventborne Alkyd
17	Interior Paints and Coatings - Other
11	Interior Wall and Ceiling Patch
538	Intermediate Feedstocks
6	Intermediates - Binders
87	Intermediates - Chemicals
16	Intermediates - Cleaner Components
72	Intermediates - Fibers and Fabrics
17	Intermediates - Foams
35	Intermediates - Lubricant Components
14	Intermediates - Oils, Fats, and Waxes
17	Intermediates - Paint & Coating Components
46	Intermediates - Personal Care Product Components

Number of Products	Category
120	Intermediates - Plastic Resins
11	Laboratory Chemicals
10	Laundry - Dryer Sheets
203	Laundry Products - General Purpose
71	Laundry Products - Pretreatment/Spot Removers
9	Lavatory Flushing Fluid
80	Leather, Vinyl, and Rubber Care Products
177	Lip Care Products
3	Lithographic Offset Inks (Heatset)
16	Loose-Fill and Batt Insulation
859	Lotions and Moisturizers
52	Lumber, Millwork, Underlayment, Engineered Wood Products
2	Masonry and Paving Systems
193	Massage Oils
24	Metal Cleaners and Corrosion Removers - Corrosion Removers
38	Metal Cleaners and Corrosion Removers - Other Metal Cleaners
29	Metal Cleaners and Corrosion Removers - Stainless Steel
64	Metalworking Fluids - General Purpose Soluble, Semi-Synthetic, and Synthetic Oils
57	Metalworking Fluids - High Performance Soluble, Semi-Synthetic, and Synthetic Oils
98	Metalworking Fluids - Straight Oils
268	Microbial Cleaning Products - Drain Maintenance Products
163	Microbial Cleaning Products - General Cleaners
191	Microbial Cleaning Products - Wastewater Maintenance Products
264	Mulch and Compost Materials
440	Multipurpose Cleaners
80	Multipurpose Lubricants
191	Oral Care Products
124	Other
40	Other Lubricants
29	Oven and Grill Cleaners
74	Packing and Insulating Materials
60	Paint Removers
79	Paper Products - Non-writing paper
160	Paper Products - Office Paper

Number of Products	Category
74	Parts Wash Solutions
75	Penetrating Lubricants
262	Perfume
22	Pest Control-Fungal-Agricultural
51	Pest Control-Fungal-Home and Garden
147	Pest Control-Insect-Agricultural
239	Pest Control-Insect-Home and Garden
3	Pest Control-Insect-Industrial
63	Pest Control-Insect-Personal
5	Pest Control-Other
15	Pest Control-Weeds-Agricultural
36	Pest Control-Weeds-Home and Garden
11	pH Neutralizing Products
2	Phase Change Materials
18	Plant Washes
2	Plastic Cards (Wallet-sized)
45	Plastic Insulating Foam for Residential and Commercial Construction
75	Plastic Products
37	Pneumatic Equipment Lubricants
13	Polyurethane Coatings
2	Power Steering Fluids
4	Printing Chemicals
29	Product Packaging
33	Roof Coatings
8	Rope and Twine
11	Rugs and Floor Mats
12	Safety Equipment
95	Sanitary Tissues
577	Shaving Products
4	Shipping Pallets
13	Slide Way Lubricants
12	Solid Fuel Additives
147	Sorbents
11	Specialty Fuels
35	Specialty Precision Cleaners and Solvents

Number of Products	Category
17	Sponges and Scrub Pads
206	Sun Care Products
2	Thermal Shipping Containers - Durable
4	Thermal Shipping Containers - Non-Durable
58	Topical Pain Relief Products
16	Toys and Sporting Gear
6	Traffic and zone marking paints
12	Transmission Fluids
5	Turbine Drip Oils
2	Wall Base
21	Wall Coverings - Commercial
16	Wall Coverings - Residential
5	Wastewater Systems Coatings
28	Wastewater Treatment Products
7	Water Capture and Reuse
39	Water Clarifying Agents
7	Water Tank Coatings
11	Water Turbine Bearing Oils
1	Window Coverings - Blinds
61	Women's Health Products
25	Wood and Concrete Sealers - Membrane Concrete Sealers
89	Wood and Concrete Sealers - Penetrating Liquids
28	Wood and Concrete Stains
50	Woven Fiber Products
15	Writing Utensils - Pens

Note: If applicable, a product may be listed in up to four categories.
Source: USDA BioPreferred Program, May 2015.