The Bio-Based Materials Automotive Value Chain

CENTER FOR AUTOMOTIVE RESEARCH

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April 2012

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April 2012

ACKNOWLEDGEMENTS

The Center for Automotive Research (CAR) would like to thank Growth Dimensions for Belvidere and Boone County Inc., and the U.S. Department of Energy for support of this work. Growth Dimensions pursued the completion of this study in order to improve its capabilities in readily identifying and facilitating business opportunities for increased market penetration of bio-based plastics, polymers, and composites into supply chains feeding the automotive industry.

This study is the result of a group effort. The authors would like to thank our CAR colleagues—Debbie Maranger Menk, Greg Schroeder, Valerie Sathe Brugeman, and Chris Hart—for their participation in meetings and assistance with content, analysis, and interpretation. Additional assistance was provided by Diana Douglass, who contributed greatly to the coordination of the project and the production of this document.

The authors would also like to thank the representatives from all of the companies that met with CAR researchers and provided insight into the bio-based materials industry. In particular, the authors would like to thank representatives at Ford Motor Company; General Motors; Bayer Material Science LLC; Cooper Standard; DuPont; International Automotive Components (IAC); Michigan State University; Ontario BioAuto Council; and University of Toronto.

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CENTER FOR AUTOMOTIVE RESEARCH

The Center for Automotive Research (CAR), a nonprofit organization, is focused on a wide variety of important trends and changes related to the automobile industry and society at the international, federal, state and local levels. CAR conducts industry research, develops new methodologies, forecasts industry trends, advises on public policy, and sponsors multi-stakeholder communication forums. CAR has carried out the majority of national level automotive economic contribution studies completed in the United States since 1992.[1] The research for this study has been performed by the Sustainability and Economic Development Strategies (SEDS) group, led by Kim Hill, associate director of research. SEDS concentrates on the long-term viability and sustainability of the auto industry and the communities that lie at the heart of both the industry and the system.

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[1] These studies include: The Center for Automotive Research. **Contribution of the Motor Vehicle Supplier Sector to the Economies of the United States and its 50 States**. Prepared for the Motor & Equipment Manufacturers Association, Ann Arbor, January, 2007. The Center for Automotive Research. **Contribution of Toyota to the Economies of Sixteen States and the United States in 2006.** Prepared for Toyota Motor North America, Inc., Ann Arbor, October, 2007. Institute of Labor and Industrial Relations, University of Michigan and the Center for Automotive Research. **Contribution of the U.S. Motor Vehicle Industry to the Economies of the United States, California, New York, and New Jersey in 2003**. Prepared for the Alliance of Automobile Manufacturers, Inc., Ann Arbor, May, 2004. Institute of Labor and Industrial Relations and the Office for the Study of Automotive Transportation, University of Michigan and the Center for Automotive Research. **Contribution of the Automotive Industry to the U.S. Economy in 1998: The Nation and Its Fifty States.** A Study Prepared for the Alliance of Automobile Manufacturers, Inc. and the Association of International Automobile Manufacturers, Inc. Ann Arbor, Winter 2001. The Office for the Study of Automotive Transportation, Transportation Research Institute, and the Institute of Labor and Industrial Relations, University of Michigan. **The Contribution of the International Auto Sector to the U.S. Economy**. A study prepared for the Association of International Automobile Manufacturers, Inc., Ann Arbor, March, 1998. McAlinden, Sean P., et. al., **Economic Contribution of the Automotive Industry to the U.S. Economy – An Update – A Study Prepared for the Alliance of Automobile Manufacturers**, Center for Automotive Research. Ann Arbor, Fall 2003. Office for the Study of Automotive Transportation, **Competitive Survival: Private Initiatives, Public Policy and the North American Automotive Industry** – Prepared for the U.S.-Canada Automotive Select Panel. University of Michigan Transportation Research Institute, Ann Arbor, June, 1992. The research staff of the Center for Automotive Research performed a number of these studies when located at the University of Michigan's Office for the Study of Automotive Transportation.

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EXECUTIVE SUMMARY

Bio-based materials are industrial products made from renewable agricultural and forestry feedstocks, which can include wood, grasses, and crops, as well as wastes and residues. These materials may replace fabrics, adhesives, reinforcement fibers, polymers, and other, more conventional, materials. This paper focuses specifically on the adoption of bio-based materials in the manufacture of automotive components and the opportunities for growing the bio-based materials industry in the Great Lakes region.

This study includes an examination of the status of current bio-based materials technology and use within the automotive industry, emerging industry trends toward deployment of bio-based materials, leading organizations that are active in the automotive bio-based materials sector, and feedstock and resource base considerations associated with production of bio-based materials. Particular attention is paid to the adoption of bio-based plastics and foams. In order to gain deeper understanding into the commercialization process, the Center for Automotive Research (CAR) has conducted three case studies. These examples of successful automaker bio-based product utilization provide a basis for understanding how a component that integrates bio-based materials is developed and how these materials move from farm to factory. Drawing on the literature review, case studies, and meetings with industry representatives, CAR has documented lessons learned and obstacles encountered and developed recommendations for increased commercialization and adoption of bio-based materials into automotive supply chains.

There are several ways bio-based materials may be used in automotive components. Beyond traditional uses (such as wood trim, cotton textiles, and leather seats), there are two primary ways these materials are used: to create polymers or as reinforcement and filler. Bio-based polymers can be made from a variety of sources—including soybean, castor bean, corn, and sugar cane—which can be fermented and converted into polymers. Bio-based composites may be reinforced or filled using natural fibers such as hemp, flax, or sisal.

Bio-based materials have been tested and deployed in a number of automotive components. Flax, sisal, and hemp are used in door interiors, seatback linings, package shelves, and floor panels. Coconut fiber and bio-based foams have been used to make seat bottoms, back cushions, and head restraints. Cotton and other natural fibers have been shown to offer superior sound proofing properties and are used in interior components. Abaca fiber has been used to make underbody panels.

These materials provide a number of benefits, but there are also costs associated with their use. Although still in its infancy, the use of bio-based materials by the automotive industry has been gradually accelerating over the last several years. The industry's new emphasis on environmentally-friendly materials and technologies has been spurred by government regulations, consumer preferences, and, in some cases, financial savings that can be realized from the adoption of these materials and technologies. After years of research, bio-based plastics are now closer to meeting or exceeding performance and cost parameters of conventional plastics than ever before. Despite these advancements, however, there are still some drawbacks which prevent bio-based materials from seeing wider application in the automotive industry. Since there is intense price competition in the automotive industry, automakers are generally unwilling to pay a premium on parts and components. Suppliers therefore must address any shortcomings of bio-based materials. Further, bio-based components must be price-neutral compared with their conventional counterparts—which is a significant challenge for a new product to overcome.

The Great Lakes region has many advantages when it comes to developing bio-based materials for use in automotive components. The region is known for both its manufacturing and agricultural production capacity. Many companies with facilities in the region are examining the potential of automotive bio-based material applications since the region grows several important crops that can be used as feedstock to produce materials. In recent years, the region has also become host to significant bio-based materials research, as well as associations interested in promoting the development of the bio-based materials industry.

Three case studies were developed by CAR to demonstrate a range of pathways to commercialize automotive components made from bio-based materials. The first case study examines the storage bin in the Ford Flex which is made of a composite that integrates wheat straw fiber reinforcement. The second case study examines the Ontario BioAuto Council, which has assisted several automotive suppliers by providing grants to assist in the commercialization process for bio-based automotive components. The third, and final, case study outlines a cooperative effort between DuPont and Denso to produce a bio-based nylon radiator end tank for the Toyota Camry.

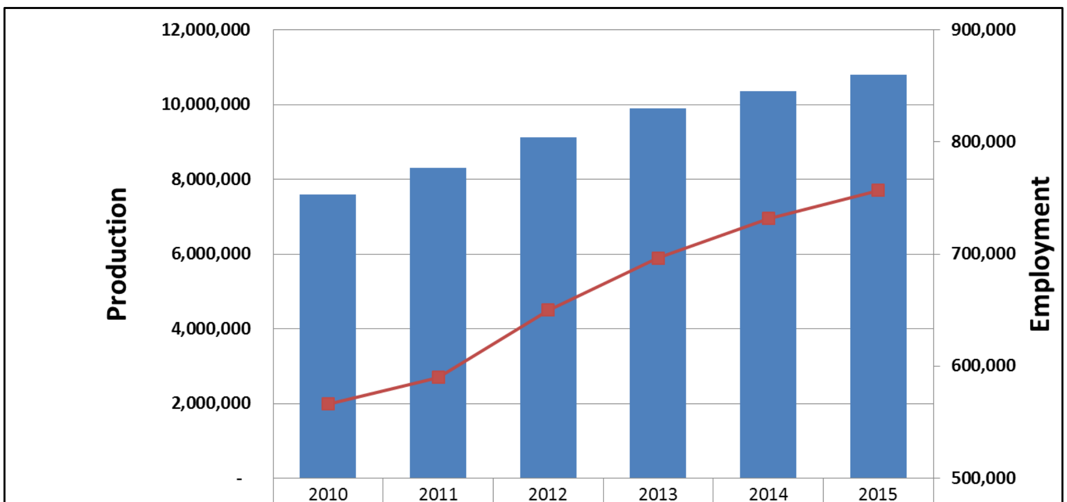
This study suggests that there is significant potential for the expansion of bio-based automotive parts and components manufacturing in the Great Lakes region. CAR has identified several successful approaches to increase commercialization of bio-based materials in automotive components. In general, the commercialization process could benefit from strong stakeholder involvement and the creation of partnerships and institutions to promote the research and institutional support necessary to overcome current barriers to implementation.

While this report provides a solid understanding of the current status of use of bio-based materials in automotive parts and components, additional inquiry is needed to understand the current and potential size of the bio-based material market in the automotive sector. Further research could examine the realistic potential of the market and investigate the maturity curve for bio-based technologies in automobiles. A supplemental study could also address in detail the role of the government in motivating the bio-based automotive market. The study could make recommendations to strategically support the development of the bio-based materials industry specific to businesses and other organizations in the Great Lakes region. Future work could also include the establishment of an automotive bio-based products network in Great Lakes region. Such a network could facilitate relationships and business development among interested stakeholders and cultivate the bio-based automotive components market.

INTRODUCTION

At the beginning of the 2000s, annual U.S. light vehicle sales peaked at 17.4 million, and remained at over 16 million units through 2007. In 2008, however, the motor vehicle bubble burst, as did other bubbles associated with debt financing. Because suppliers, dealers, and assemblers expanded capacity during the early part of the decade, many were vulnerable when sales suddenly began to decline. Employment in the automotive industry had been declining since the early 2000s, but this decline accelerated in the 2008-2009 recession years as automakers and suppliers rationalized capacity. In the past few years, the automotive industry has shown signs of recovery; annual U.S. light vehicle sales reached their lowest point in 2009 and have been increasing since. Over the next several years U.S. based automotive production is forecasted to steadily increase as can be seen in Figure 1, which displays a forecast for both automotive production and employment.

Figure 1: U.S. Vehicle Production & Automotive Manufacturing Employment Forecasts

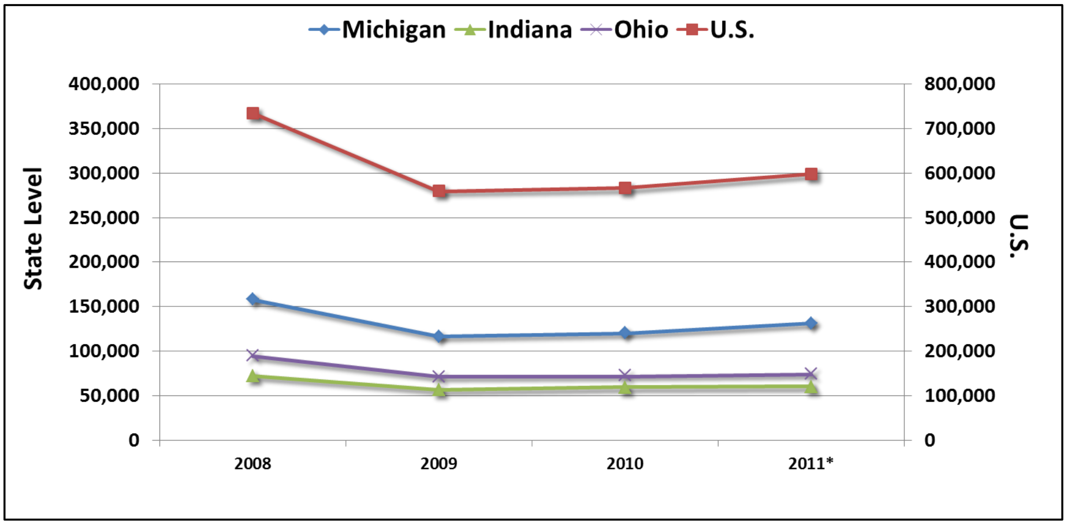


	2010	2011	2012	2013	2014	2015
Vehicle Production	7,592,725	8,308,448	9,120,972	9,892,417	10,358,185	10,803,687
Automotive Employment	566,400	590,000	650,000	696,400	731,600	756,800

Source: IHS Global Insight 2011; BLS 2011; and CAR 2011

It can also be seen in Figure 1 that along with automotive production, automotive employment is expected to increase over the next several years. In fact, automotive employment is already on the recovery, reaching its lowest level for the U.S. in 2009 and increasing since. Figure 2 displays the recent increase in national automotive employment as well as recent trends in automotive employment in Michigan, Indiana, and Ohio.

Figure 2: Motor Vehicle & Parts Manufacturing Employment 2008-2011



Source: BLS 2011 ***Note: 2011 figures are through October***

Despite the smaller market, the U.S. automotive industry is estimated to be a $370 billion industry for 2011, and the majority of this value is in the automotive parts sector. This implies that penetrating even a small portion of this industry could provide significant returns to investment in new materials and technologies, such as bio-based automotive parts and components, if these technologies are successfully adopted by the industry.

Bio-Based Materials and the Bio-Economy

According to the 2008 Farm Act, a bio-based product is a "commercial or industrial product (other than food or feed) that is composed in whole or in significant part of biological products, including renewable domestic agricultural and forestry materials, or an intermediate ingredient or feedstock" (USDA 2010). The emerging concept of the "bio-economy" includes biofuels (ethanol and biodiesel), bioenergy (landfill gas and biomass), and biomaterials (organic solvents and biopolymers) (Mid-Michigan Bio-Alliance 2011).

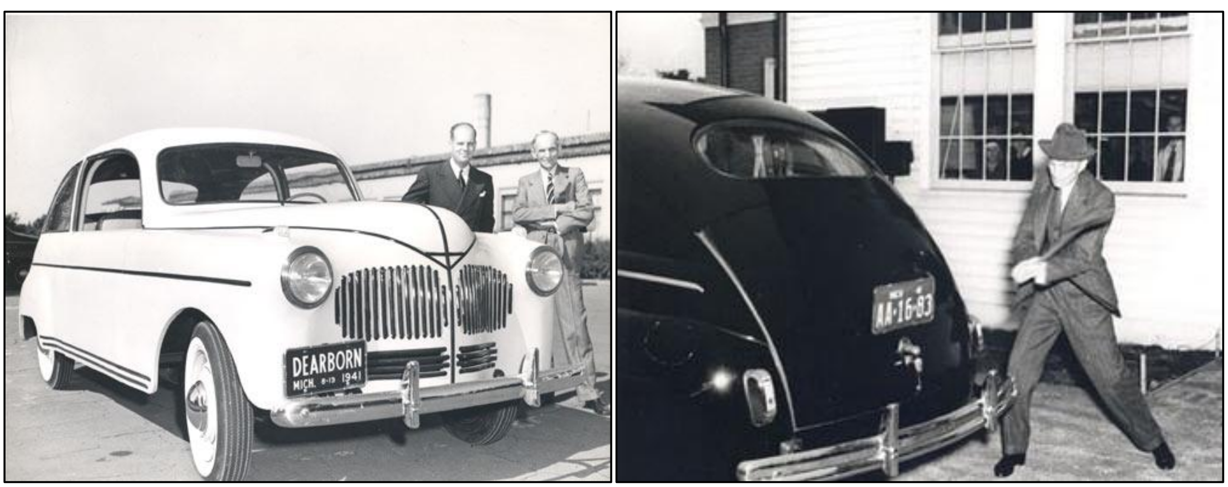
Many different industry sectors expect to have a major stake in the bio-based economy, including biotechnology, agribusiness, energy, automotive, aerospace, information technology, chemical, and many other interrelated businesses. As the bio-economy develops, these sectors will need to be able to understand the complexities of agricultural production and take advantage of promising new technologies utilizing agricultural materials as a feedstock (Singh et al. 2003). This paper focuses specifically on the adoption of bio-based materials in the automotive industry and opportunities for growing the bio-based materials industry in the Great Lakes region.

Bio-based materials are industrial products made from renewable agricultural and forestry feedstocks. These feedstocks can include wood, grasses, and crops, as well as wastes and residues (Mohanty et al. 2002) and may replace fabrics, adhesives, reinforcement fibers, polymers, and other conventional materials. Renewable and conventional materials can be combined to produce components; for instance, a bio-based composite could be composed of a petroleum-based polymer but use renewable fibers as reinforcement—replacing some or all of the conventional glass reinforcement fibers.

History

In the 1930s, bio-based materials were in use in the production of vehicle parts and components. Henry Ford used bio-based materials in paints, enamels, and molded plastic parts. Ford also used soybeans, hemp, wood pulp, cotton, flax, and ramie in various components (Crawford 2009), and in 1941, Ford unveiled a car that had soy-based plastic body panels (Phillips 2008). Figure 3 shows Ford's famous "soybean car," which integrated many bio-based materials. The car's body integrated straw, flax, and soybean meal and its tires were made from goldenrod latex. The image on the left shows Ford and Robert Boyer, one of the company's top soybean researchers, with the soybean car. The image on the right shows Ford demonstrating the strength and resilience of bio-based plastics by swinging an axe and having it bounce off the trunk of his personal car, which had been modified with a bio-based plastic rear deck lid.

Figure 3: Ford's 1941 Soybean Car



Source: Henry Ford Museum 2011

Decades later, in the 1960s, coconut fibers were used in car seats and wood flour fillers were used in polypropylene composites for interior parts (Aparecido dos Santos et al. 2008). The use of bio-based materials in components gained traction in the early 1990s. Work to include these materials involved replacing glass fibers with plant fibers in composites for automotive parts and components (Ashori 2008). During this period, advances in bio-based material technology involved mostly non-structural interior applications. Bio-based materials were introduced in several vehicles, first in Europe and later in North America and were used to manufacture components such as door panels, package trays, seat backs, and trunk liners (Brosius 2006).

Bio-based materials have been utilized broadly in the food and medical industries. Food-related applications include beverage bottles, containers, cups, disposable tableware, and packaging. Taking advantage of the properties inherent to bio-based materials, medical applications include the production of disposable equipment and tools designed for easy decomposition (Sindhupak 2007). As of 2007, 65% of bio-based plastics were used in packaging and food related applications. This share is estimated to shrink to just 40%, as automotive and electronics applications, which have a higher profit potential than the packaging and food industries, are expected to gain market share, reaching over 25% by 2025 (Harlin and Vikman 2010).

Study Objectives

Encouraging bio-manufacturing and its associated value chain development, and building upon its current expertise in producing conventional parts for automakers, may position the Great Lakes region at a global competitive advantage as oil prices climb, and the demand for more bio-based parts increases. The objective of this study is to assist in identifying business opportunities for increased market penetration of bio-based products into the automotive supply chain. To strengthen and underpin this effort, CAR researchers met with representatives from numerous organizations around the Great Lakes region, employed a literature search, and leveraged available resources, including data sets.

The study includes an examination of: the status of current bio-based materials technology and use within the automotive industry, emerging industry trends on deployment of bio-based materials, leading organizations (automakers, suppliers, educational institutions, and associations) active in the automotive bio-based materials sector, and feedstock and resource base considerations within the Great Lakes region. In order to gain deeper understanding into the commercialization process, CAR conducted three case studies. The examples of successful automaker bio-based product utilization provide a basis for understanding how a component integrating bio-based materials is developed and how these materials move from farm to factory. From these case studies, CAR has documented lessons learned and obstacles encountered and developed a roadmap for increased commercialization and use of bio-based materials in the automotive supply chain.

Processes and Materials Basics

In order to use a new material in a vehicle component, it must first go through a vigorous approval process. The approval process begins with a new material being developed and considered for use in a part or component. The initial development work needed to consider using a new material could originate internally from the automaker's own research, development, design, and engineering teams or externally from a supplier.

Once a new material has been identified, its potential applications are considered, and the required specifications for the material (based on intended application) are determined. These specifications consist of specific properties that a material must have in order to be used, e.g. density, elongation, tensile strength, heat and chemical resistance, cost, etc. All materials being considered for a particular application must display all of the required characteristics for the specific application's specifications regardless of their source or feedstock and companies are not willing to compromise on any of the specification requirements, including cost. The automotive sector is enormously capital intensive and risk averse – this culture of conservatism has resulted in bio-based materials being adopted cautiously in selected non-critical applications until the technology is fully proven and totally cost competitive with existing materials.

After the application specific specifications have been determined for the material, it must then be tested to ensure that it meets specifications, and if the results are positive, the material is sent to the engineering team to create a prototype design for the performance-testing phase. If the material passes in performance tests, it then goes through the sourcing and purchasing process, where it must meet the goals of cost effectiveness and sustainable production levels.

The length of time for the approval process varies significantly depending on the situation. Sometimes a supplier has highly developed material and a component that has gone through significant testing; in this case, the earlier steps of the automaker approval process may be expedited. On the other hand, a material application might require several attempts before it is finally approved, thus lengthening the approval process. Above all, program timing is essential, and deadlines for a product might significantly impact the amount of time it takes for a particular material application to be introduced for use in a vehicle.

Composites combine a polymer matrix (which can be either bio-based or petroleum-based) with fiber reinforcement (which can be conventional or natural fibers). In order to produce the composite, a fabrication process must be developed, and in order to insure proper adhesion in the matrix, fibers may need to undergo a surface treatment (Drzal 2011). The surface treatment of fibers is particularly important when natural fibers are used, because hydrophilic (having a tendency to mix with, dissolve in, or absorb water) natural fibers and hydrophobic (having a tendency to resist or repel water) polymer matrices are frequently incompatible. The purpose of the surface treatment is to chemically modify the fibers so they can properly combine with the matrix (Njuguna et al. 2011). A bio-based composite may utilize a bio-based polymer, a bio-based fiber, or both.

To modify material properties and meet customer specifications, additives (colorants, coupling agents, stabilizers, blowing agents, reinforcing agents, foaming agents, and lubricants) are also used in materials (Ashori 2008). Material characteristics such as fiber-matrix adhesion, mechanical properties, moisture, impact and fatigue, and thermal stability are frequently included in material specifications (Njuguna et al. 2011), though each material and application will have its own unique specifications.

BIO-BASED MATERIALS USAGE

Most Common Materials

There are several ways bio-based materials may be used in automotive components. Beyond traditional uses—such as wood trim, cotton textiles, and leather seats—there are two primary ways these materials are used: as reinforcement and filler or to create polymers. Bio-based composites may be reinforced or filled with natural fibers including bast fibers, which come from the stem of plants that are specifically grown for fiber (such as hemp, kenaf, flax, and jute); fibers from a variety of wood sources or crop residues; or leaf fibers such as sisal, abaca, and banana fibers.

Bio-based polymers can be made from a variety of sources including soybean, castor bean, corn, and sugar cane. These feedstocks are usually fermented and go through a series of conversions to produce polymers that can be used in plastic composites. Just like their conventional counterparts, bio-based polymers can be extruded, blown, molded, injection-molded, foamed, and thermoformed.

Natural fiber fillers and reinforcements are the fastest growing polymer additive (Ashori 2008). In the past 15 years, natural-fiber composites have been adopted by the European automotive industry (Holbery and Houston 2006); in recent years, these materials have been gaining traction in the United States. Use of castor and soy-based polyols for interior foams has now become more widespread as well.

Bio-based materials have been tested and deployed in a number of automotive components. Flax, sisal, and hemp are used in door interiors, seatback linings, package shelves, and floor panels. Coconut fiber and bio-based foams have been used to make seat bottoms, back cushions, and head restraints. Cotton and other natural fibers have been shown to offer superior sound proofing properties and are used in interior components. Natural latex is used to enhance the safety of interior components by making the surfaces softer. Abaca fiber has been used to create under-floor body panels (Holberry and Houston 2006).

Current Usage

Automotive components that incorporate bio-based materials have been used by many automobile manufacturers around the world, including Audi, BMW, Chrysler, Fiat, Ford, General Motors, Honda, Mazda, Mercedes Benz, Opel, Peugeot, Renault, Toyota, Volkswagen, and Volvo (Ashori 2008 and CAR 2011). The materials used in the manufacture of these vehicles are frequently sourced domestically. Natural fiber producers in North America are already supplying automotive manufacturers—including Chrysler, Ford, and General Motors—with bio-based materials for use in components, such as door panels, dashboard components, and headliners (Burgess 2004).

The most common components that have been made with bio-based materials include door panels, seat backs, package trays, dashboards, headliners, trunk liners, and other interior trim parts. There have been few exterior or under-the-hood applications, though Toyota has used natural fibers in its exterior tire covers and under-the-hood radiator end tanks. Another example of a bio-based material in an exterior application is the use of flax fibers in car disk brakes to replace asbestos fibers (Ashori 2008). In another exterior application, Rieter Automotive has manufactured underbody panels for Mercedes using abaca fibers to replace glass reinforcement.

In recent years, there also have been attempts to use natural fiber composites in structural applications—an area which has previously been the reserve of synthetic fibers like glass and aramid (Njuguna et al. 2011). Some researchers are interested in combining natural fibers with nano-materials to develop structural components that could potentially be used in automotive components. Though exterior, under-the-hood, and structural applications are more limited and frequently still in various stages of research, they represent some of the more high-technology and high-value applications of bio-based materials and could potentially become an important part of the market.

Announced Usage

Most automakers have not publically stated specific targets for use of bio-based materials in their vehicles. The exception is Toyota, which announced in 2008 that it plans to replace 20 percent of the plastics used in its automobiles with bio-based plastics by 2015 (Otani 2008). Ford has internal goals for renewable materials usage by department, but these goals are not numeric, because it is difficult to predict when the materials will be available at competitive cost and quality. Ford has, however, modified its specifications requiring suppliers to include a minimum amount of bio-based content in seat foams. Ford's modification has ensured the automaker will continue to use these materials in its products into the future.

One way automakers initiate the use of new materials is by including them in concept vehicles. Several years ago, Ford unveiled its Model U concept car, which included several bio-based components—including soy-based seating foam and body panels and corn-based floor mats, canvas roof material, and tires. Ford is now using soy-based seating foam in all of its North American vehicles. Other concept vehicles integrating bio-based materials include the Honda FCX concept fuel cell vehicle, which uses corn-based interior fabrics; the Toyota ES3 concept car, which uses sweet potatoes and sugar cane in interior components; and the Toyota "i-unit" and "i-foot" concept vehicles which use kenaf fiber in their body structure. The Hyundai "i-flow" concept uses Ultramid® Balance, a product from BASF that is composed of 60 percent renewable materials. These material choices reflect potential consideration of bio-based components for actual production models in the future.

Automaker Information Description

Many components use natural fibers such as flax, wood, coconut, and wheat straw as reinforcement in polypropylene composites, and bio-based foams are also penetrating the market. Some composites use corn or castor oil to produce the polymer matrix. Several components that integrate bio-based materials are displayed in Table 1 below (a more complete list of vehicles can be found in Appendix C). The components in the table demonstrate the diversity of the materials found in vehicles today, as well as the range of companies from all over the world which are implementing bio-based materials in their vehicles. Some of the top automakers include Daimler, Ford, and Toyota—each with their own unique focus on various materials and applications.

Table 1: Selected Bio-Based Automotive Components

Model(s)	Feedstock	Material	Application
Cadillac DeVille	Wood	Polypropylene	Seatbacks
Chevrolet Impala	Flax	Polypropylene	Trim, rear shelf
Ford Flex	Wheat straw	Polypropylene	Interior storage bins
Ford Focus BEV	Coconut	Polypropylene	Loadfloor
Ford vehicles (Multiple)	Soy	Polyurethane	Foam seating, headrests, headliner
GMC Terrain	Cotton, kenaf	Polyester	Acoustic insulator, ceiling liner
Honda Pilot	Wood	N/A	Floor area parts
Lexus CT200h	Bamboo, corn	Polyethylene terephthalate, Sorona	Luggage-compartment, speakers, floor mats
Mazda 5 Hydrogen RE Hybrid	Corn	Polylactic acid	Console, seat fabric
Mercedes-Benz A-Class	Abaca/banana, flax, other natural fibers	Composite material	Underbody panels, seatbacks, spare tire cover
Mercedes-Benz C- and A-Class	Flax	Polyethylene	Engine and transmission cover, underbody panels
Toyota Prius	Corn	Sorona EP	Instrument-panel, air-conditioning vent
Toyota Raum	Kenaf, starch	Composite material	Floor mats, spare tire cover

Source: CAR 2011

In Europe, the automaker that has been doing the most work on bio-based materials is Daimler, through its Mercedes-Benz brand. Mercedes has integrated a wide variety of natural fibers in its vehicles—including flax, hemp, sisal, wool, abaca, cotton, and jute fibers. These fibers have been used in over 50 different parts and components (Holbery and Houston 2006), including spare-wheel compartment covers, underbody panels, seat backrests, engine and transmission covers, rear panel shelves, and door trim panels, and have been installed in Mercedes-Benz A-, C-, E-, and S-Class models. Figure 4 shows some of the components for the Mercedes-Benz E-Class that utilize bio-based materials.

Figure 4: Mercedes-Benz E-Class with Bio-Based Components

Source: Holbery and Houston 2006

Other European automakers such as BMW, Fiat, and Volkswagen, are also using bio-based materials in their product offerings. Volkswagen's Audi A2 uses flax and sisal fiber-reinforced polyurethane composites in door trim panels, and the BMW 7-Series uses sisal in an acrylic polymer for door trim panels. Fiat has recently announced it will use fuel lines made of nylon derived from castor oil in several vehicle models. Ford and GM have also integrated bio-based materials into their European product offerings. The European Ford Fiesta was the first vehicle to use corn-based Goodyear tires and the European Ford Focus and Freestar integrated natural fibers into their interior door panels. Now that vehicles like the Fiesta and Focus have global platforms, bio-based materials are being implemented around the world. General Motors' Opel brand has released its Astra/Vectra model with door trim panels and seat backs that use hemp, kenaf, and flax fibers.

In North America, Ford and General Motors have also pursued the use of bio-based materials. Ford is using soy-based foam seating in all of its North American models and the Ford Escape has a soy-based headliner. Ford is also using engineered ebony wood trim in its Fusion, Taurus SHO, and several Lincoln vehicles and a kenaf-reinforced polypropylene composite in interior door panels for the Focus, Fiesta, and Mondeo models. Ford worked with the Ontario BioCar Initiative in Ontario to develop a wheat straw fiber-reinforced plastic material that is now used to manufacture a storage bin for the Ford Flex. In the GMC Terrain, General Motors uses cotton as an acoustic insulator and kenaf in the ceiling liner. The Chevrolet Impala has a flax-reinforced polypropylene composite in a rear shelf component. The Saturn L300 used kenaf and flax in package trays and door panel inserts. General Motors has also made use of wood fiber in the Cadillac DTS's seatbacks and in the cargo area floor of the Chevrolet Trailblazer and GMC Envoy. Chrysler has also used natural fibers in its vehicles; the 2001 Sebring had a natural fiber-reinforced polypropylene composite in it over a decade ago.

In Asia, Toyota is a leader in bio-based materials adoption. The Toyota Prius and SAI use corn-based plastic in interior components such as instrument panels, air conditioning system outlets, ceiling surface skins, sun visors, and pillar garnishes. The Toyota Raum uses starch and kenaf fibers in a composite material for the spare tire cover and floor mats and a castor oil-based nylon jointly developed by Denso and DuPont is used in the Camry's radiator end tank. Several Lexus vehicles use bio-based plastics with kenaf and bamboo fiber reinforcement for interior components such as the luggage compartment, speakers, carpeting, package shelves, luggage-trim upholstery, cowl-side trim, door scuff plate, tool box area, floor finish plate, and seat cushions.

Other Asian automakers such as Honda and Mazda are also using bio-based materials in their vehicles. The Honda Pilot uses wood fiber in floor area parts and the Mazda 5 Hydrogen RE Hybrid uses corn-based plastics in its console and seat fabric.

Bio-Based Content in Automotive Components

The bio-based materials currently in use vary significantly—not just in the type of material used and its application, but also in terms of the renewably-sourced content in the material. Renewably-sourced content might vary from a few percent to well over half of the total content of the material. The portion of renewably-sourced content in selected automotive components can be seen in Table 2.

Table 2: Bio-Based Content of Selected Automotive Components

Model(s)	Feedstock	Material	Application	Bio-Based Content[2]
BMW 7-Series	Sisal	Acrylic polymer	Interior door panel	70 percent
Chrysler Sebring	Kenaf, hemp	Polypropylene	Interior door panel	50 percent
Ford Fiesta and Focus	Kenaf	Polypropylene	Interior door panel	50 percent
Ford Fusion and Lincoln MKZ	Soy	Polyurethane	Seating headrests	13 to 16 percent
Lincoln MKZ	N/A	Polyurethane	Console door	20 to 90 percent
Multiple Fiat vehicles	Castor	Zytel	Fuel lines	60 percent
Nissan Leaf	Corn	Sorona	Floor mats	20 to 37 percent
Toyota Camry	Castor	Zytel	Radiator end tank	40 percent

Source: CAR 2011

Ford's soy-based headrests are 13 to 16 percent bio-based by weight and 13 to 26 percent by volume (SPE 2011b). The kenaf and hemp-reinforced polypropelene composite used by Chrysler is composed of 25 percent kenaf, 25 percent hemp, and 50 percent polypropelene (Bingham 2000). Some Ford vehicles contain interior door panels made of a 50 percent kenaf fiber-reinforced polypropelene composite (Fernyhough and Markotsis 2011), while the interior door panel used by BMW is composed of an acrylic polymer with 70 percent sisal fiber loadings (Njuguna et al. 2011, SPE 2009). The bio-based nylon used in both Toyota's radiator end tank and Fiat's diesel engine fuel lines has 40 to 60 percent renewable content (DuPont 2011a, SPE 2009, SPE 2011b). DuPont's Sorona, which has been used in a variety of components including floor mats, instrument-panels, air-conditioning system outlets, ceiling surface skin, sun visors, and pillar garnishes, has a bio-based content between 20 and 37 percent (DuPont 2010).

Standards for Determining Bio-Based Content and Environmental Impact

Currently, there are no standards in place regulating what can and what cannot be called a bio-based material. Companies wishing to include the bio-based content of a product in their marketing need an objective way to determine both the environmental impacts of using various materials in their products, as well as a method for quantifying the portion of their product that is bio-based in a way that will give legitimacy to the figures used. This is why standards organizations such as the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO) have developed standards for measuring bio-based content and conducting life cycle assessments (LCAs). Relevant standards include:

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[2] Sources were frequently unclear on whether bio-based content was measured by weight or volume; in this table, bio-based content was measured by weight when that information was available. For more information on the renewable-content of specific parts and components, please consult the sources documented in the paragraph following this table.

ASTM Standards (ASTM 2011)

- D6866 (2011) Test Methods to Determine the Bio-based Content of Materials Using Radiocarbon and Isotope Ratio Mass Spectrometry
- D7026 (2004) Guide for Sampling and Reporting Results for Determination of Bio-based Content of Materials via Carbon Isotope Analysis
- D7075 (2004) Standard Practice for Evaluating and Reporting Environmental Performance of Bio-based Products

ISO Standards (ISO 2011)

- ISO 14040 (2006) Environmental management - Life cycle assessment - Principles and framework
- ISO 14044 (2006) Environmental management - Life cycle assessment - Requirements and guidelines

The bio-based materials industry already uses these standards to demonstrate the benefits of using these materials and to verify the materials' renewable content. The difficult issue is determining how to create a labeling system for complex products (such as automobiles) that integrate numerous components. It is not currently feasible to make a significant portion of an automobile out of bio-based materials, and it may never be feasible to make some components out of bio-based materials. A voluntary labeling program could, however, be beneficial to promote the expanded use of bio-based materials in automobiles.

The U.S. Department of Agriculture (USDA) would like to eventually include automobiles under a voluntary bio-based materials labeling program and the Society of Automotive Engineers (SAE) has led the way by facilitating a dialogue between various stakeholders on the issue. USDA's Biopreferred Program has two major initiatives: the voluntary product labeling initiative and the preferred federal procurement initiative (USDA 2011). The product labeling initiative allows companies to put an official "USDA Certified Bio-based Product" label on bio-based products that meet certain requirements, and the preferred federal procurement initiative specifies federal agencies' purchasing preferences for categories of products that contain approved bio-based products. ASTM International has been selected to provide certification for the voluntary labeling program and will determine the portion of renewable content which can be displayed on labels for each product (Brooke 2011). Bio-based products will be tested by an outside laboratory according to ASTM standard D6866, which will determine the proportion of the product derived from renewable resources.

After significant consideration, the USDA set the applicable minimum bio-based content requirement at 25 percent for inclusion in the labeling program (USDA 2011). The renewable content of bio-based foam in automobiles had originally been only 5 to 10 percent; however, it is currently possible to use bio-based foams composed of over 30 percent renewable materials. Similarly, bio-based composites are frequently well over 25 percent renewably-sourced, and many components already in today's vehicles could be considered "bio-based" using a 25 percent minimum content requirement. In CAR's meetings with representatives from industry, several individuals mentioned that in the automotive industry, 25 percent minimum renewable content was considered a reasonable metric for considering a material bio-based.

Automobiles are considered complex assemblies, which are not currently included in either of the two USDA Biopreferred initiatives. Issues preventing complex assemblies from being included in the USDA initiatives include the development of an acceptable test procedure to determine the bio-based content and the appropriate content and placement for the certification mark (Federal Register 2011). The Center for Industrial Research and Service (CIRAS) at Iowa State University has been working to catalogue companies that produce, distribute, and test bio-based products; managing the certified bio-based product labeling program; disseminating information on the program; and educating procurement personnel about the program and bio-based products (CIRAS 2011).

Similar to the federal program, many states (including Illinois, Indiana, and Ohio) have passed legislation establishing preferential procurement for bio-based products. In 2007, the Midwestern Governors Association set the foundation for creating a bio-based product procurement initiative as part of its Energy Security and Climate Stewardship Platform for the Midwest (Marthaler 2008).

At the SAE "2011 Workshop to Characterize Biobased Materials in Vehicles for the USDA BioPreferred Program," USDA and CIRAS representatives discussed their work to characterize the bio-based content of complex assemblies, specifically bio-based automotive components. The workshop was designed to advance the dialogue between automotive manufacturers and suppliers, the USDA, and other relevant organizations regarding the current state of the use of bio-based materials in vehicles and the potential implications of the USDA BioPreferred Program for the auto industry (SAE 2011).

FEEDSTOCKS & RESOURCES

Materials

There are a variety of feedstocks that can be used to produce bio-based materials. Beyond traditional uses—such as using wool and cotton for textiles, wood for paneling or leather for interior covers—renewable feedstocks are largely used in two ways. The materials can be used as basic chemical ingredients that are fermented and converted into polymers, replacing the petroleum used in plastics and foams. Alternately, fibrous plants such as kenaf, hemp, or sisal can be used to replace conventional fillers and reinforcements like fiberglass and talc, which are used in composites.

The most common feedstocks used to create bio-based polymers for automotive components are castor beans, soybeans, corn, and sugar cane. Bio-based polymers can be produced through the conversion of plant sugars or by using microorganisms to metabolize feedstocks. Soy is being used to make automotive interior foams for a variety of vehicles, and castor oil is the base for a variety of molded, injected, and extruded parts as well as for carpets, mats, and textiles.

Natural fibers are classified into groups which have similar properties—such as bast (or stem), leaf, seed/fruit, and stalk (Njuguna et al. 2011). Bast fibers (e.g. flax, hemp, jute, and kenaf) are strong and stiff, giving them the ability to support great loads before failing, while leaf fibers (e.g. sisal, pineapple, and abaca) are tough, giving them the ability to absorb large amounts of energy before failing. Seed or fruit fibers (e.g. cotton, kapok, and coir) have elastomeric toughness, but are not structural (Brosius 2006). Because all of these properties are useful for different reasons, different types of fiber will be appropriate for different applications, and a blend of various types of fibers may be useful in some situations. Several different fibers and polymers are listed in Table 3, along with associated physical properties—including density, elongation, and tensile strength. The most common natural fibers used in automotive components are flax, kenaf, and hemp, which are all bast fibers that can be used to displace fiberglass fibers as reinforcement in composites. Many natural fibers can provide equal or better performance compared to conventional reinforcement fibers, while reducing product weight due to their lower densities.

After being harvested, natural fibers must go through a process called retting, which uses moisture, microorganisms, or chemicals to separate the fiber from other plant components like hemicellulose and lignin (Holbery and Houston 2006). The fibers can then be treated to alter their properties and make them more suitable for insertion into composites.

Besides the fibers themselves, other components are useful. Lignin is an organic substance that binds together cells, fibers, and vessels in wood. It can be used in adhesives or as a polymer additive. The U.S. Department of Energy (DOE) and Oak Ridge National Labs (ORNL) have invested in research to produce low cost carbon fiber using lignin as part of an initiative to produce multiple value added streams from biological feedstock and lightweight components for vehicles. The DOE and ORNL have partnered with companies including Lignol Innovations and Kruger Wayagamack from Canada and Innventia from Sweden in lignin research (Baker 2010).

Table 3: Mechanical Properties of Selected Fibers and Polymers

Fiber	Density	Elongation	Tensile Strength
Fibers (reinforcements)			
Cotton	1.5-1.6	7.0–8.0	287–800
Jute	1.3	1.5–1.8	393–773
Flax	1.5	2.7–3.2	345-1035
Hemp	1.5	1.6	690
Ramie	1.5	1.2–3.8	400–938
Sisal	1.5	2.0–2.5	511–635
Coir	1.2	30	175
Viscose (cord)	–	11.4	593
Soft wood (kraft)	1.5	–	1000
E-glass	2.5	2.5	2000–3500
S-glass	2.5	2.8	4570
Aramide (normal)	1.4	3.3–3.7	3000–3150
Carbon (standard)	1.4	1.4–1.8	4000
Polymers (resins/matrices)			
ABS	1.05	10	55
Polycarbonate	1.22	100	62
Polyethermide	0	–	105
Nylon	1.12	29	66
Polyethylene (HDPE)	0.95	30	28
Polypropylene	0.9	200	35
Polystrene (high impact)	1.05	15	35
Epoxy resin	–	6.2	32

Source: Ashori 2008

For a more complete list of feedstocks that can be used to make bio-based materials for automotive components, see Table 4. Within the table, bio-based feedstocks are divided into categories based on type of feedstock (bast, leaf, seed/fruit, stalk, and wood fibers, among others) and function (filler/reinforcement, polymer matrix, and traditional use).

Table 4: List of Bio-Based Material Feedstocks and Functions

Feedstock	Type	Function
Wool	Animal fiber	Filler/reinforcement, traditional use
Leather	Animal hide	Traditional use
Flax	Bast fiber	Filler/reinforcement
Hemp	Bast fiber	Filler/reinforcement
Jute	Bast fiber	Filler/reinforcement
Kenaf	Bast fiber	Filler/reinforcement
Ramie	Bast fiber	Filler/reinforcement
Rattan	Bast fiber	Filler/reinforcement
Castor beans	Chemical feedstock	Polymer matrix
Corn	Chemical feedstock	Polymer matrix
Soybeans	Chemical feedstock	Polymer matrix
Sugar cane	Chemical feedstock	Polymer matrix
Sweet potatoes	Chemical feedstock	Polymer matrix
Abaca	Leaf fiber	Filler/reinforcement
Banana	Leaf fiber	Filler/reinforcement
Curaua	Leaf fiber	Filler/reinforcement
Henequen	Leaf fiber	Filler/reinforcement
Manila	Leaf fiber	Filler/reinforcement
Palm	Leaf fiber	Filler/reinforcement
Pineapple	Leaf fiber	Filler/reinforcement
Sisal	Leaf fiber	Filler/reinforcement
Coconut (coir)	Seed/fruit fiber	Filler/reinforcement
Cotton	Seed/fruit fiber	Filler/reinforcement, traditional use
Kapok	Seed/fruit fiber	Filler/reinforcement
Bamboo	Stalk fiber	Filler/reinforcement
Barley	Stalk fiber	Filler/reinforcement
Corn	Stalk fiber	Filler/reinforcement
Grass	Stalk fiber	Filler/reinforcement
Rice	Stalk fiber	Filler/reinforcement
Wheat	Stalk fiber	Filler/reinforcement
Wood	Wood fiber	Filler/reinforcement, traditional use

Sources: Holbery and Houston 2006, Brosius 2006, Chen et al. 2005, Njuguna et al. 2011, Rosato 2008, Aparecido dos Santos et al. 2008

Feedstock Geography

The geographic distribution of the various feedstocks is an important factor in determining whether these materials are viable or even desirable for use in the automotive industry. Many of the benefits that can be derived from using renewably-sourced materials rely on where crops are grown. One of the benefits of using these materials, for instance, is local economic development and creation of additional revenue streams for farmers in the region. These benefits will only materialize if the feedstocks for the materials can be grown locally. In addition, transportation costs can affect how far a material can be shipped and remain cost competitive, and transportation over longer distances also means greater energy consumption and potentially negative environmental impacts, decreasing the sustainability aspect of using bio-based resources.

Biological feedstocks are generally a very low value per ton and are not easily transportable like conventional feedstocks such as oil or natural gas. As a result, biological feedstocks cannot economically be hauled very far before being processed in a manner that concentrates the useable portions of the feedstock material and adds value. Thus feedstock production for bio-based materials will generally be a localized activity in which the feedstock is processed in relatively small facilities that are in relative proximity to growing operations. Because of these limitations, the bio-based material production process will require careful planning and business modeling to ensure that the economic case for the venture is solid. In addition, each feedstock must be assessed for its optimal usage and processing parameters.

The following sections discuss the geographic distribution of various crops that are used to produce polymers and natural fibers that could be used in automotive components. The sections highlight several crops that are already grown in the Great Lakes region and thus represent regional strengths.

Geographic Availability of Bio-Based Polymer Feedstocks

Previous sections have referenced the use of crops like castor beans, soybeans, corn, and sugar cane to produce polymers for automotive components. This subsection discusses the current geographic distribution of several of these crops. While the Great Lakes region has a history of producing some crops like soybeans and corn, other crops such as castor beans and sugar cane are traditionally grown in other regions of the world, such as South and East Asia and South America, and therefore must travel a long distance to end up in North American vehicles. The climate required to grow some feedstocks used in bio-based materials means that it may never be feasible to grow these plants within the region, or even in North America.

The castor bean plant is primarily grown in Asia—especially India, China, Vietnam and Thailand. There is also some African cultivation in Ethiopia and Kenya. In the Americas, the major countries cultivating the castor bean plant are Brazil, Paraguay, Ecuador, and Haiti (Ramankutty 2008). Figure 5 displays the regions where the castor bean plant is grown.

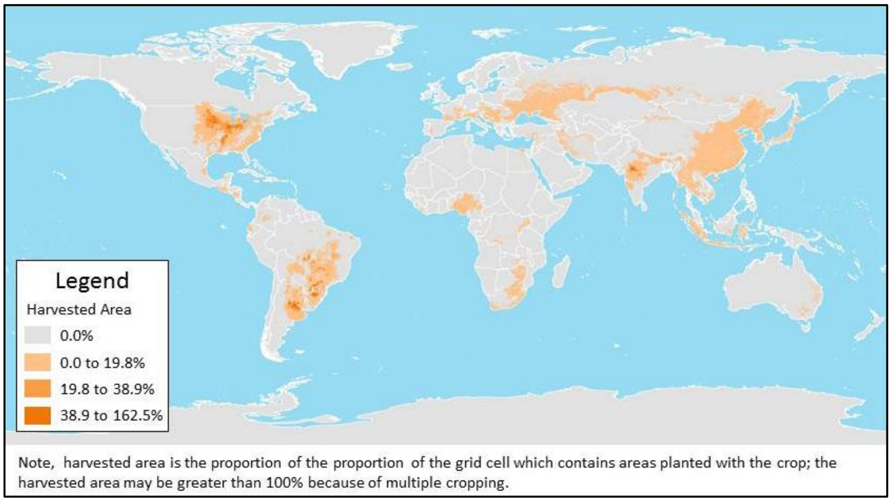
Figure 5: Regions Where Castor Beans are Grown

Note, harvested area is the proportion of the proportion of the grid cell which contains areas planted with the crop; the harvested area may be greater than 100% because of multiple cropping.

Source: Ramankutty 2008

The country producing the greatest amount of soybeans globally is the United States, which is responsible for approximately a third of the world's soybean production. The U.S. is followed by Brazil and Argentina, which together produce nearly half of the world's soybeans. Other large producers include China, India, Paraguay, and Canada (FAOStat 2007). Figure 6 displays the global density of soybean production. An important point to note is that within North America, soybean production is centered around the Great Lakes region, which is also host to major automakers and auto parts suppliers. This means that when soybeans are used to produce polymers for automotive components, production can remain largely in the region, further reducing environmental impact and transportation costs. Indeed, production within the region is so high, and the geographical connection between manufacturing and soybean production is so strong, that the National Soybean Board has worked with automakers to find higher value uses for excess soybeans.

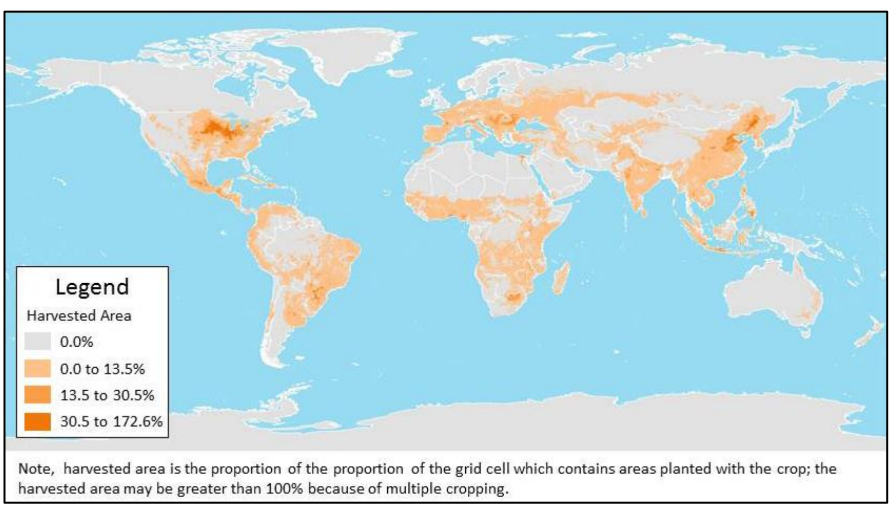
Figure 6: Regions Where Soybeans are Grown



Source: Ramankutty 2008

The United States is also the largest corn producer globally, responsible for over 40 percent of the world's annual production. China and Brazil are distant followers, responsible for around 20 percent and 15 percent of global corn production, respectively. Other large corn producers include Mexico, Argentina, India, France, Indonesia, and Canada (FAOStat 2007). Again, as with soybeans, significant corn production within North America is located in the Great Lakes region, and facilitating connections with the region's traditional manufacturing sector and corn producers could result in regional economic development opportunities benefitting farmers and manufacturers. Figure 7 displays regions of the world where corn is harvested.

Figure 7: Regions Where Corn is Grown



Source: Ramankutty 2008

The United States is the largest oil crop producer overall, producing nearly 18 percent of the world's oil crops. The U.S. is followed by Brazil, which produces around 14 percent of the world's oil crops and China, which produces 11 percent (FAOStat 2011).

Producing around one third of the world's sugar cane, Brazil is the largest sugar cane producing country. It is followed by India, which produces around 22 percent of the world's sugar cane and China, which produces around 7 percent.

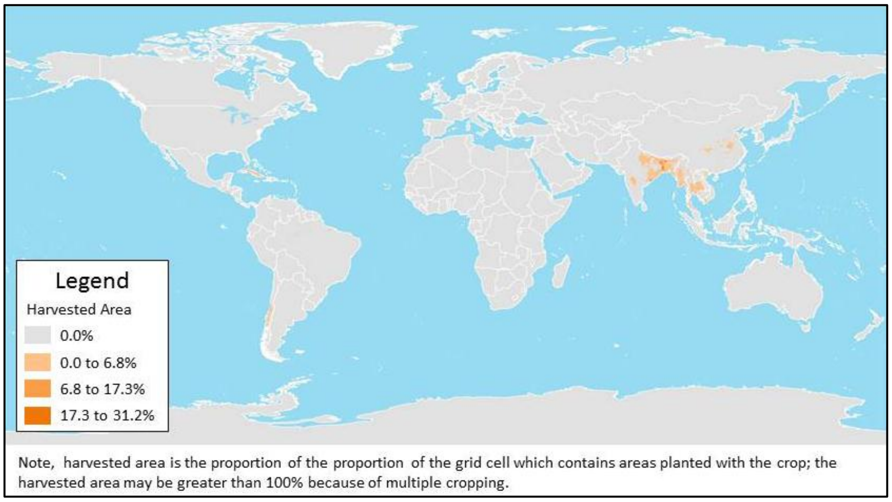
North America produces a variety of crops in abundance, including soybeans, corn, and other oil crops that can be used to create polymers for automotive components. These crops are grown in relatively high concentration in the North America and in the Great Lakes region in particular. Other crops, such as castor beans and sugar cane, are largely produced on other continents, and their inclusion in automotive components for North American vehicles means geographically longer supply chains.

Geographic Availability of Bio-Based Natural Fiber Feedstocks

Previous sections have referenced the use of natural fibers like hemp, jute, kenaf, sisal, and wheat straw in automotive components. This subsection discusses the current geographic distribution of several of these crops. While the Great Lakes region has a history of producing some crops like wheat, many others such as jute, kenaf, abaca, and sisal are traditionally grown in other regions in the world such as South Asia, Central and South America, and Africa.

Jute is primarily grown in Southern Asia. Countries like India, Bangladesh, China, Myanmar, and Vietnam are responsible for a large portion of production (FAOStat 2007). Jute-like fibers (which include kenaf) are primarily produced in India, Russia, China, and Thailand. In recent years, however, there has been a push to grow and process kenaf in the Southeastern United States (Burgess 2004). Figure 8 displays regions of the world where jute and jute-like fibers are harvested.

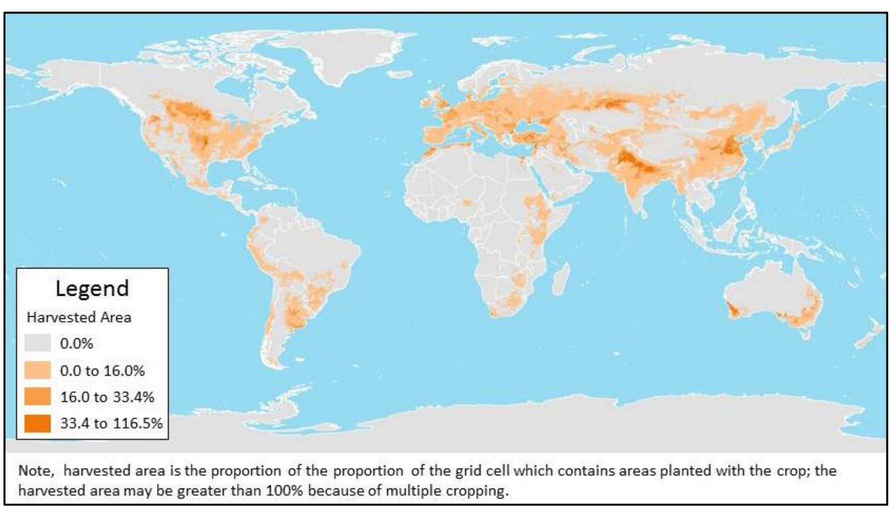
Figure 8: Regions Where Jute and Jute-like Fibers Are Grown



Source: Ramankutty 2008

Wheat straw is another material that has been used as natural fiber reinforcement. It is particularly attractive because it is a crop residue that is already produced as a byproduct of food production, and thus does not compete with other crops. China is the largest producer of wheat, with around 18 percent of world production, followed by India at around 13 percent, the United States at 9 percent, Russia at 8 percent, and France at 5 percent (FAOStat 2007). Production in North America is concentrated to the west of the Great Lakes region, but wheat production occurs throughout the region as well. Figure 9 displays regions of the world where wheat is harvested.

Figure 9: Regions Where Wheat is Grown



Source: Ramankutty 2008

The majority of the world's abaca is grown in the Philippines. Other producers include Ecuador, Costa Rica, and Indonesia (FAOStat 2007). Nearly two thirds of the world's cotton is produced by China, India, and the United States, with China producing over 30 percent and India and the United States producing around 17 percent each. Brazil is the world leader on the production of sisal and is responsible for around two-thirds of global sisal production. Most of the remaining sisal is produced in the African countries of Tanzania, Kenya, and Madagascar.

North America produces a variety of fiber crops in abundance, such as wheat and cotton, which can be used to create polymers for automotive components. Other crops such as jute, kenaf, abaca, and sisal are largely produced on other continents and their inclusion in automotive components for North American vehicles means geographically longer supply chains. Some of these crops could potentially be grown in North America; for instance, small quantities of kenaf and hemp are already produced in some regions of the continent.

Ancillary Issues at Higher Volumes

Representatives at automakers and suppliers have voiced concerns about using agricultural and forestry products as feedstocks to produce materials for automotive parts and components. Automakers and suppliers are concerned about the competition between materials and food and the need to consider all of the impacts from using a particular material.

One of the most salient issues at higher material production volumes is that of competition with food. This issue is particularly salient due to the impact the ethanol fuel program in the United States has had on the price of corn. If materials for automotive components are based on agricultural products, then their use could compete with the production of food in two ways: first, if a material is made out of a product that could potentially be eaten, such as soybeans or corn, then higher material production volumes could potentially drive up food prices, and second even if a crop is only useful for materials, such as jute or hemp fibers, cultivation of these crops could potentially displace food crops.

Counterarguments to the issue of food competition include the observation that, in the United States, the federal government pays farmers a subsidy to abstain from growing crops in fields. If fields are not currently producing food, then cultivating crops to be used for industrial materials would result in greater societal benefits. In addition, for crops such as soybeans and corn, which are grown in massive quantities in the United States, there are agricultural associations that work to discover new higher value uses of these crops. Large quantities of these crops are produced each year, which means that using them to produce industrial materials might not compete with food production in a detrimental manner. It is worth noting, however, that this argument only makes sense for vehicles produced in North America; for vehicles produced in other parts of the world, it may be inappropriate to use feedstocks that compete with food.

Companies can use lessons they have learned from the use of bio-based materials that use food crops as a feedstock to advance their knowledge of other bio-based feedstocks. This knowledge can be used in manufacturing vehicles in other parts of the world.

In assessing the value of using renewably-sourced materials, it is important to look at the net impact of exchanging one material for another. Using life-cycle assessment (LCA), the total impact of a product or process choice can be discerned. LCA calculates impacts across the entire life of a product, from raw material extraction through materials processing, manufacture, distribution, use, maintenance, and disposal. Common metrics emphasized in LCA include energy use, greenhouse gas emissions, and pollution measures. While using bio-based materials may have benefits in terms of reducing energy expenditures and greenhouse gas emissions associated with material extraction and end of life stages, if these materials are sourced globally, the environmental costs of transporting them may diminish the overall environmental gains.

BIO-BASED MATERIALS TRENDS IN THE AUTOMOTIVE INDUSTRY

The automotive industry's adoption of bio-based materials has been gradually accelerating over the last several years. The industry's new emphasis on environmentally-friendly materials and technologies has been spurred by government regulations, consumer preferences, and, in some cases, financial savings that can be realized from the adoption of these materials and technologies. In this way, bio-based materials face some of the same challenges to broader adoption that are also faced by alternative powertrain technologies and alternative fuels (many of which are also bio-based). Environmentally-friendly materials and technologies hold the promise of accelerated adoption, as costs drop due to economies of scale made possible by high volume production. This promise of lower costs with increased volumes holds as true for lithium-ion batteries as it does for bio-based floor mats.

Drivers and Benefits

The drivers and benefits of adoption of bio-based materials in the automotive industry can be roughly categorized as regulatory, economic, company policy-related, and product-specific, and in some cases, the benefits cut across multiple categories. Adoption of bio-based automotive components may also be driven by concerns not yet realized but expected in the future, such as forecasted petroleum price increases or expected regulation of material recyclability.

Regulatory Drivers

The U.S. government has not been as aggressive as the European Union (EU) in requiring automakers to use bio-based materials, promoting recyclability of vehicle components, or requiring automakers to take responsibility for vehicle disposal at the end of a vehicle's service life. Several Asian governments, however, have released stringent requirements that are comparable to those found in Europe. Because automakers operating in the United States also function in those markets, the development of bio-based materials will help the companies meet the governmental requirements they face around the world, even if the requirements in the United States are not as stringent. There is a trend of increasing reliance on global vehicle platforms as well as an increased frequency of global contracts for parts and components sourced from suppliers. These developments will further accelerate the adoption of bio-based components that are developed in one market into all of the other markets in which a given automaker sells.

Although stricter recyclability and end-of-life regulations may appear in the United States in the future, government regulations related to fuel economy are already driving the adoption of bio-based materials. Particularly when used as fillers (replacing materials such as glass or talc), bio-based fibers result in materials that can be lighter than their conventional counterparts. Use of lighter weight materials is expected to help automakers meet the stringent 54.5 mile per gallon (mpg) 2020 fuel economy standard recently agreed upon by the Obama administration and automotive companies.

Economic Drivers and Benefits

The rise of petroleum prices over the last several years has been the chief economic driver of the adoption of bio-based plastics in the automotive industry. Likewise, the anticipation of future petroleum price increases is frequently cited as a key to making bio-based plastics cost competitive with conventional counterparts in the future. In recent years, petroleum prices have fluctuated considerably, making it difficult for automakers and suppliers to price their products. In an industry where product lifecycles and supply contracts last for many years, fluctuations in petroleum prices can impact profitability. Increased use of bio-based plastics is therefore seen as a hedge against both the rising cost of petroleum and the fluctuations in price it brings.

In most cases, research has indicated that bio-based materials currently cost more than their conventional counterparts. Automakers are generally not willing to pay a premium for bio-based materials and require them to be on par with conventional counterparts in terms of price, performance, and durability. Some bio-based material solutions have been implemented specifically because they were less expensive than their conventional counterpart, for instance. The case study provided in this report on the bio-based radiator support developed by Denso is a key example. Denso approached Toyota with a new bio-based solution because it would result in financial savings compared to the petroleum-based plastic Denso had already been supplying for that component.

Proponents of bio-based materials hope that, as petroleum prices rise and bio-based materials become less expensive due to increasing economies of scale, these cases will become increasingly prevalent. While crop production and manufacturing of parts and components have arguably already attained economies of scale, certain portions of the value chain could be scaled up to reduce prices. For instance processing and compounding of agricultural inputs, if done at a larger scale, could result in lower unit costs of materials. Likewise, increased volumes will likely drive vertical integration in the automotive bio materials supply chain, further reducing cost.

Company Policy-Related Drivers and Benefits

Many automakers have adopted company-wide sustainability policies that highlight the firm's environmental responsibilities to both its employees and the public. These firms also believe that the adoption of these policies, which may include the increased use of bio-based materials, will improve their image in the eyes of consumers, who have over time shown increased awareness of environmental issues.

Although virtually every automaker has a corporate sustainability policy, few define goals specifically for bio-based materials content. One exception is Toyota, which has gone on record with plans to replace 20 percent of the plastics used in its automobiles with bio-based plastics by 2015 (Otani 2008). The previous section dealing with current applications of bio-based plastics provides details on other automakers' uses of bio-based materials.

Automakers are generally not willing to pay a premium for bio-based materials, and require them to be on par with conventional counterparts not only in terms of price but also in a variety of performance and durability metrics. In those cases where a company-wide sustainability policy addresses bio-based materials adoption, these products may potentially receive greater consideration for new applications. Specifications, for example, can be written so they either favor the adoption of a component that uses bio-based materials or simply do not exclude a component due to the usage of standard terms and conditions initially developed for conventional materials.

Product-Specific Drivers and Benefits

In many cases, bio-based plastic products are adopted not only for their environmentally-friendly image, but also because they have specific advantages over their conventional counterparts that make them preferable for a given application. As technology advances, suppliers expect these benefits—along with cost reductions made possible by increasing economies of scale, to drive increased adoption of bio-based components—as opposed to "soft" drivers such as projecting an environmentally-friendly corporate image.

As previously mentioned, bio-based plastics generally make use of bio-based materials in one of two ways: either as a replacement for a petroleum-based polymer or as a replacement for less environmentally-friendly fillers (such as glass or talc). When a bio-based oil is used to replace a petroleum-based oil, total carbon footprint can be reduced. The carbon released from these materials represents no net addition to the atmosphere, since any carbon present was sourced from the ambient air around the given plant, as opposed to being extracted from the ground. When a locally-sourced, bio-based product is used, a further carbon footprint reduction is enabled, due to the elimination of transport of petroleum-based materials, which may come from as far away as the Middle East.

Bio-based components also have several inherent qualities that may make them a superior choice, as compared to their conventional counterparts for specific applications. Because bio-based fillers (such as wheat straw) tend to be less dense than traditional fillers (like glass or talc), components that use these materials are lighter than their conventional counterparts. Given the automotive industry's increasing focus on lightweighting vehicles (which is partially driven by recently approved fuel economy requirements), this characteristic is expected to stimulate the adoption of bio-based components in the future.

Bio-based components also offer additional benefits that can be of critical importance in specific applications. They tend to absorb energy from crashes and crush on impact, for example, as opposed to shattering into shards, as conventional plastics typically do (Burgess 2004), which makes them safer to vehicle occupants in the case of a crash. Depending on the application, bio-based components typically have strength and rigidity comparable to those made of conventional materials, which opens the door to use in a wider variety of applications, particularly for non-structural components.

Bio-based plastics also have characteristics which make them easy to work with in the manufacturing environment. They are typically safer to handle than conventional materials, such as glass, and are less likely to cause skin and respiratory irritation among employees who handle them (Kim and Lee 2009). Because equipment used in the manufacturing of bio-based plastic components typically runs at a lower temperature than in the manufacture of petroleum-based plastic components, energy savings can be realized. The production of natural fiber suitable for composites, for example, is about 60 percent lower in energy consumption than the manufacture of glass fibers (Brosius 2006). Likewise, the amount of energy consumed in the production of a glass fiber mat is more than five times higher than for a flax fiber mat (Njugana et al. 2011). Bio-based materials also tend to be less abrasive than conventional ones (e.g., glass), and therefore cause less wear to manufacturing equipment. Also, because bio-based plastics have qualities very similar to their conventional counterparts, a supplier can usually use the same equipment for both types of plastic in the production process, without need for new capital expenditures.

Drawbacks and Challenges

After years of research, bio-based plastics now come closer to meeting or exceeding performance parameters and cost of conventional plastics than ever before. Despite these advancements, however, there are still some drawbacks which prevent wider application in the automotive industry. Bio-based plastic components must therefore overcome any performance or manufacturing shortcomings, while being price-neutral with their conventional bio-based counterparts—a significant challenge for a new product to overcome.

Product-Related Drawbacks and Challenges

Bio-based plastic parts are typically marginally less strong and rigid than their conventional counterparts. While not necessarily a critical factor for a variety of applications (particularly those in the interior of the vehicle), it does limit the use of bio-based plastics for certain structural components. Even though bio-based plastic components can be treated to make them more repellant to water, they are still more likely to be damaged by moisture than their conventional counterparts. Water absorption has been shown to permanently weaken components made of bio-based materials (Panthapulakkal and Sain 2007), which has limited their use in exterior applications.

Bio-based plastics are subject to the seasonal and geographic differences found in the plants from which they are made. Weather, climate, soil, and other factors can alter the qualities of a given plant oil or fiber, making it necessary for suppliers to monitor these materials and adapt their manufacturing processes as necessary (Njugana et al. 2011). Likewise, these natural variations, particularly among filler materials, can cause natural variation in the appearance and texture of components made from bio-based materials. This characteristic has made automakers reluctant to use bio-based plastics in the parts of the interior with which consumers have the most interaction and which are most visible (the "Class A" surfaces). Class A surfaces, therefore, are more likely to use a bio-based plastic with a bio-based polymer, as opposed to a bio-based filler for instance, since it is less likely to vary the appearance and texture of the components.

It is possible that, over time, the variation in texture and appearance that may occur in bio-based plastic components could be seen by automakers and consumers as a positive attribute. Wood-covered dashboards, for example, exhibit significant pattern and color variation from one vehicle to the next. Many buyers have learned to associate these variations with uniqueness and exclusivity, and view them positively. The possibility exists for this perspective to eventually be applied to bio-based door inserts, headliners, and other Class A surfaces.

Bio-based materials have unique negative characteristics, such as odor issues and increased susceptibility to moisture and heat damage, as well as not being sufficiently flame-retardant. Because of these characteristics, automakers test bio-based plastic components to failure modes beyond those set for traditional petroleum-based plastic components. While these extra steps ensure the consumer does not suffer any negative impact from the decision to use bio-based materials, they do increase the performance challenges bio-based plastic components must overcome in order to achieve greater penetration in the automotive industry.

Manufacturing Environment Drawbacks and Challenges

As mentioned above, bio-based materials are subject to the seasonal and geographic differences found in the plants from which they are made, making it necessary for suppliers to monitor these materials and adapt their manufacturing processes as necessary. Likewise, bio-based plastic fillers are more sensitive than their conventional counterparts to high temperatures, which can break down their inner structure. This characteristic limits their use in applications that require high temperature manufacturing processes. This can be a positive attribute in processes that do not require high temperatures; however, since it may result in energy savings and shorter processing times as discussed in the previous section.

Most polymers, especially thermoplastics, are hydrophobic (water repelling) substances, which are not compatible with hydrophilic (water absorbing) bio-based fillers. In order to enable the use of bio-based fillers with these polymers, chemical ‘‘coupling’’ or ‘‘compatibilizing’’ agents need to be used. Although the addition of these agents does not add a great deal of complexity, it does add cost (Ashori 2008). This drawback is a good example of challenges of working with bio-based materials that are avoided when conventional counterparts are used.

In many cases, even when a bio-based plastic achieves cost parity with its conventional counterpart, a supplier electing to use the material can incur changeover costs that can make the transition less financially viable. In order to switch to the new bio-based material, the supplier’s machines must be stopped and completely purged of the old, conventional raw material, which adds costs related both to employee time necessary to perform the work and to equipment downtime. This is not always the case, however, as some bio-based polymers enable “drop in” operation where they can replace a conventional material with no modifications to manufacturing equipment.

Business Environment Drawbacks and Challenges

Because certain bio-based products use inputs that are also consumed as food, there are also political challenges to overcome in using these products without competing with agriculture intended for food. In many cases, an optimal solution can be achieved where the edible portion of a plant is consumed as food, while the inedible portions are used for bio-based materials applications. This is true in the case of wheat straw, which uses wheat stalks that would normally be discarded. Even when a bio-based plastic application uses a crop that isn’t edible, concerns can still arise as the land used to grow the crop could conceivably have been used to grow an edible crop for human consumption. Suppliers of bio-based feedstocks have been careful to avoid these issues. Recent objections related to the use of corn in ethanol production, which was said to drive up the cost of corn used in food and other applications, has made many bio-based materials companies very careful in how they approach their raw materials sourcing strategy.

The current supply chain for automotive bio-based parts and components is representative of one expected for a newly introduced technology. Even though activity is increasing, relatively few firms have released products, so competition to drive down prices is limited. Likewise, raw materials producers have kept prices high, as they face limited competition. Because volumes are still relatively low, companies have not engaged in a high degree of vertical integration, which has made them more reliant on outside providers—a further driver of high prices. The hammer mills and compounding facilities necessary for processing wheat straw, for example, could be acquired and run by the same supplier if higher volumes justified the investment. Without this vertical integration, each of these processes is performed by an outside firm, which adds its own margin and cost to the product.

As bio-based plastics products are implemented in a wider array of vehicles and production grows, price pressures are expected to be alleviated. There is an expectation among the automotive suppliers providing these products that higher production volumes will start a cycle of reduced costs, which will then further drive increased implementation.

Because many bio-based components are new to the industry, there are typically fewer suppliers of a component or a given raw material than there are for conventional petroleum-based components. Automakers typically structure their specifications to have multiple sources of given components and raw materials to minimize the risk of supply chain disruptions. These policies have slowed the adoption of bio-based materials in the industry, since it is often difficult to locate multiple suppliers in the emerging bio-based materials industry. The adoption of bio-based materials may be delayed or limited until the supply chain can overcome its shortcomings and satisfy automotive sector policies and practices on materials performance and cost and address the issue of multiple supply paths for production security.

GREAT LAKES ACTIVITY

The Great Lakes region has many assets that make it an attractive region for the development of bio-based materials and automotive components. This section discusses numerous organizations within the region—including universities, associations, automakers, suppliers, and agricultural and chemical companies—that are active in developing and promoting bio-based materials for automotive applications. This list is for illustrative purposes only and is by no means an exhaustive compilation of all the organizations in the region that are involved with the bio-based automotive components industry.

Educational Institutions

Many educational institutions in the Great Lakes region are involved with bio-based materials research. Universities in Ontario have aggressively pursued automotive bio-based materials research programs. The universities of Toronto, Waterloo, Windsor, and Guelph, in particular, have each distinguished themselves for research into automotive applications of bio-based materials. These universities have created research centers such as the University of Waterloo Centre for Automotive Research, the University of Guelph Bioproducts Discovery and Development Centre, and the University of Toronto Centre for Biocomposites and Biomaterials Processing.

Michigan State University has also conducted significant research into bio-based materials, through the MSU Bioeconomy Network, the MSU Bioeconomy Institute, the Composite Materials and Structures Center, and the Composite Vehicle Research Center. The MSU Bioeconomy Network coordinates MSU's research, policy and economic analysis, education, corporate and government collaborations, and commercialization efforts to promote Michigan's bioeconomy. The MSU Bioeconomy Institute, located in Holland, Michigan, supports biofuels, bio-based chemicals, and biomaterials research and commercialization. The Composite Materials and Structures Center at MSU researches and tests polymer composites, has the capacity to conduct testing and analyses on materials and focuses on research into composite structures for lightweight, durable, and safe vehicles.

Ohio State University is also contributing to bio-based materials research through its Ohio BioProducts Innovation Center (OBIC), whose mission is to accelerate commercialization of bio-based products. Established in 2005 with funding provided by the Ohio Third Frontier Program, OBIC creates connections between various parts of Ohio State University to facilitate commercialization of bio-based products.

Associations

In Ontario, two automotive bio-based materials partnerships among universities, industry, and government have been created: the Ontario BioCar Initiative and the Ontario BioAuto Council. The BioCar Initiative is a research collaboration between four universities and several industry partners. Funding for BioCar comes from the universities, industry, and the Ontario government. The BioAuto Council is an industry-led organization that links various industry sectors with an interest in the automotive bio-based materials supply chain. The Council also assists in reducing the risk of investing in the commercialization of bio-based materials. These associations will be discussed in detail later in this report.

Similarly, AUTO21 is a partnership organized by the Canadian government that brings together universities and industry across Canada to conduct practical automotive-related research in a number of key focus areas including health, safety and, injury prevention; societal issues; materials and manufacturing; powertrains, fuels, and emissions; design processes; and intelligent systems and sensors. AUTO21 has supported work in automotive bio-based materials applications; AUTO21 has actually been the key funder of much of the bio-materials research for automotive applications in Canada since the organization was established in 2001. AUTO21 has funded an entire series of bio-materials work at Canadian universities. For instance, Dr. Amar Mohanty from the University of Guelph and Dr. Mohini Sain from the University of Toronto led a project called "Renewable, Recyclable and Lightweight Structural Prototype Parts," which focused on bio-based materials (AUTO21 2011). AUTO21 assisted in the start-up of the Ontario BioCar Initiative and helped found the Ontario BioAuto Council.

In Michigan, the Mid-Michigan Bio Alliance has taken on a role similar to the BioAuto Council in Ontario. The Bio Alliance is a partnership between the Prima Civitas Foundation (a nonprofit group that brings together networks of knowledge assets to create a more competitive, innovative, and global Michigan) and Capital Area Michigan Works (a Lansing area workforce development agency) that works to bring together various stakeholders including public, private, academic, and government entities in a collaborative effort to further bio-based interests in mid-Michigan.

The Michigan Biopreferred Products Association is another Michigan-based group which promotes sustainable products. The association provides a range of benefits to manufacturers, developers, retailers, and distributors, including programs, promotion, and up-to-date information on various bio-based products and services (MBPA 2011). Besides offering benefits directly to members, the Michigan Biopreferred Products Association informs decision makers on relevant public policy issues and educates the public about bio-based products and services made, distributed, and sold in Michigan.

The Michigan Soybean Promotion Committee (MSPC) is financed through money collected during the sale of Michigan soybeans and assists the Michigan soybean industry in research, education, and promotional activities for the soybean industry. In 2010, 21 percent of total MSPC spending was dedicated towards finding new uses for soybeans (MSPC 2011). The MSPC has worked with Michigan companies including Ford, Dow Automotive, Lear, and Johnson Controls to develop soy bio-based products (Weldon 2011).

PolymerOhio, Inc. is an association focused on enhancing global competitiveness and growth for Ohio-based polymer businesses. Funded by member dues and the Ohio Department of Development, the group provides businesses with value-added programs and services and connects businesses to academic institutions, economic development resources, and service providers (PolymerOhio 2011a). As part of its work, PolymerOhio has created a network of bio-based research and industry collaborators that includes universities, laboratories, government agencies, farm companies, agribusiness associations, and polymer suppliers (PolymerOhio 2011b).

In Indiana, the Indiana Biobased Products Advisory Commission was created by the Indiana state legislature in 2007 to recommend policies and strategies to promote the use and development of bio-based products in the state. The commission met during four months in 2008 and produced a report of recommendations (ISDA 2008).

Groups like the Society of Automotive Engineers (SAE) and the Society of Plastics Engineers have been involved in the automotive bio-based materials industry, mostly by sponsoring conferences featuring bio-based materials as a focus subject. For several years now, the Society of Plastics Engineers has held a bio-based materials session at its SPE Automotive Composites Conference (SPE 2011), and these sessions attract several speakers and papers each year. The SAE's Vehicles Materials Task Force of the Green Technology Systems Group recently hosted a workshop on the current state of bio-based materials in vehicles (SAE 2011).

There are also groups that have been created specifically to bring new products to market and assist in bridging the gap between research and commercialization of bio-based materials. Some examples of these types of organizations include the Sustainable Chemistry Alliance, Green Centre Canada, and the Composites Innovation Centre (CAR 2011). These organizations tend to promote networking between various groups and sometimes serve as a source of capital by investing in the commercialization of bio-based technologies and processes. Frequently the focus is on technologies that have moved beyond the university research and concept stages and into the piloting stage.

Automakers

The region's automakers have all begun including bio-based materials in their products. Ford has been working with universities and suppliers in the Great Lakes Region to develop these materials, and has created its own division dedicated to developing bio-based materials. Ford is including soy-based polyurethane foams in all of its North American vehicles (Ford 2010) and has been working to integrate natural fibers in various components as well. General Motors has integrated several different natural fibers (such as kenaf, flax, and wood) in its vehicles that are produced in the Great Lakes region (Holbery and Houston 2006, General Motors 2011). Chrysler was the first automaker to use EcoCor—a bio-based composite developed by Johnson Controls that contains kenaf, hemp, and polypropylene—in the door panels of its Sebring (Berenberg 2001). Toyota is also active in the region and is using a bio-based nylon developed by Denso and DuPont.

Suppliers

Several suppliers in Ontario have utilized funding from the Ontario BioAuto Council to commercialize bio-based materials: Canadian General Tower produces interior trim coverstock, which is produced using plant oils; GreenCore Composites supplies natural fiber that reinforces resins; Magna is developing a loadfloor that uses a recycled cardboard honeycomb core sandwiched between layers of soy-based polyurethane composite with natural fiber reinforcement; and Woodbridge Foam produced a bio-based headliner for multiple vehicles.

Companies with facilities and offices in Michigan—such as BASF, Cooper Standard, Denso, Faurecia Interior Systems, Federal Mogul, IAC, Johnson Controls, Lear, SABIC Innovative Plastics, and Visteon—have also been working on bio-based products. For instance, IAC molded a storage bin for the Ford Flex that used a wheat straw fiber-reinforced composite and Cooper Standard developed the AgriSeal inner belt component that uses the same material. Cooper Standard's original seal component used steel, which was replaced with polypropylene for weight reduction and cost savings; the polypropylene was then replaced with a polypropylene-wheat straw composite from A. Schulman, a resin compound supplier, for further weight reduction. The final component weighed significantly less (56 percent weight reduction) and provided cost savings (7 percent cost reduction overall) (Otremba 2011). Johnson Controls does much of its work on bio-based products at its campus in Holland, MI. Globally, Johnson Controls has a portfolio of seven different natural fiber/polymer composites that are currently manufactured. Over 60 percent of the base polymer for BASF's Ultramid® Balance product is made from sebacic acid derived from castor oil, and Faurecia uses natural fibers in door panel structures.

Ohio is also host to several suppliers who are producing bio-based materials—such as A. Schulman, Ashland Performance Materials, and Findlay Industries. A. Schulman is the compounder of the wheat straw fiber-reinforced composite that is being used by both IAC and Cooper Standard. Ashland has its own bio-based product line that uses soybeans and corn to produce polyester resins. Findlay Industries uses natural fibers (such as flax, kenaf, and sisal) to make door panels and headliners.

The Dutch company DSM, which produces bio-based resins for the automotive industry, has many locations throughout the United States, including several in Michigan, Indiana, and Illinois. Cereplast has a bio-based plastic resin facility in Seymore, Indiana that produces hybrid resins specifically for the automotive industry. FlexForm Technologies, which is based in Indiana, produces EcoCor, which was used by Johnson Controls (based in Wisconsin) to produce door panel inserts for the 2001 Chrysler Sebring. Bulk Molding Compounds, Inc., in Illinois, has a line of bio-based composites that use vegetable oil based resins, recycled fillers, and natural and organic fiber reinforcements.

Agricultural and Chemical Industries

The Great Lakes region's agricultural and chemical industries are among its greatest assets when it comes to developing the bio-based materials industry. Some food and forestry companies have become manufacturers of bio-based fuels, chemicals, and plastics, including Archer Daniels Midland (ADM) and Cargill (Langeveld et al. 2010). Chemical companies, such as Dow Chemical Company and DuPont, are also closely involved with the development and use of bio-based materials.

ADM, an agricultural product conglomerate, created an alliance with PolyOne Corporation to develop bio-based plasticizer technologies. Plasticizers are used to make plastics softer and more flexible and are especially important for materials used in automotive interior components. Cargill, a major producer and marketer of food and agricultural products and services, created a subsidiary, Durafibre, which is a commercial processor of natural-based fibers. Durafibre provided the flax straw that was used to create the rear shelf of the 2000 Chevrolet Impala. Cargill also partnered with BioAmber to commercially produce bio-based succinic acid, a building block for polymers and resins, at its new plant in Sarnia, Ontario. NatureWorks LLC is a Cargill spinoff that produces renewable plastics.

Dow Chemical Company produces soybean oil-based polyols which are used to produce foams for various applications, including seating, headliners, arm rests, headrests, and consoles. DuPont has been extremely active in developing bio-based materials; in addition to working with Denso to jointly develop a radiator end tank using bio-based nylon, DuPont has several bio-based product offerings, including Zytel which is derived from castor oil, Sorona which is derived from corn, and Hytrel which is also derived from corn (Bell and Szanto 2010).

CASE STUDIES

The Center for Automotive Research has developed three case studies that detail the commercialization of bio-based materials in automotive components. The case studies in this section were selected because they were high profile and demonstrate a range of pathways to commercialize automotive components made from bio-based materials. The section will include information on:

1. Wheat Straw Reinforced Composite in a Storage Bin of the Ford Flex
2. Bio-Based Material Commercialization Fund Managed by the Ontario BioAuto Council
3. Castor Oil Based Nylon in the Radiator End Tank of the Toyota Camry

The first case study examines the adoption of a storage bin in the Ford Flex which is made of a composite that integrates wheat straw fiber reinforcement. The bio-based storage bin is the result of collaboration between members of the Ontario BioCar Initiative. The second case study examines the Ontario BioAuto Council, which has assisted several companies that are supplying bio-based materials to the automotive industry by providing them with grants to assist in the commercialization process. The third and final case study outlines work done between DuPont and Denso to produce a radiator end tank made of bio-based nylon material for the Toyota Camry.

The work that has been done to deploy the material technologies in these case studies is spreading and changing the industry. The wheat straw fiber-reinforced composite, for instance, is expected to enter production soon in seals made by Cooper Standard, and the compounder A. Schulman is investigating other applications. Similarly the nylon resin used in the radiator end tank is now being used to create fuel lines for diesel engines in Fiat vehicles. In addition, the Ontario BioAuto Council Investment Fund led to the development and commercialization of several products from multiple companies across Ontario.

Case Study 1: Wheat Straw Fiber-Reinforced Composite in a Storage Bin of the Ford Flex

As mentioned, Henry Ford was an early adopter of bio-based materials in his vehicles; the first Ford Model-T ever built had a steering wheel that used straw as reinforcement material, and the straw was sourced from Ford's own farm (Schut 2010).

When wheat is harvested, the wheat straw is left behind as a byproduct. Wheat straw is typically associated with low value uses, such as animal feed and livestock bedding. Much of the wheat straw produced is discarded (Ford Sustainability Report 2009/2010). Ontario produces a significant amount of wheat straw and has an estimated 30 million metric tons available at any given time (Deligio 2010).

The material developed for use in the Ford Flex combines wheat straw with polypropylene, a thermoplastic polymer. When straw is added to the composite, it serves as filler—replacing some of the polypropylene, reducing petroleum content, or it can be used as reinforcement—replacing materials like glass fibers or talc, and reducing material weight (McIntosh 2010). In the component for Ford, the wheat straw is used as reinforcement (Ford Sustainability Report 2009/2010). The composite used to create the component for Ford is made of 20 percent wheat straw fiber and 80 percent polypropylene injection molding compound (Schut 2010).

The wheat straw-reinforced polypropylene was used to create a third row quarter storage bin and cover liner for the 2010 Ford Flex (Schut 2010). The bin can be seen as an individual component (left) and within the context of the Flex interior (right) in Figure 10 below. The material and storage bin were developed by Ford, academic researchers from Canadian universities, compounder A. Schulman from Ohio, and wheat straw fiber supplier Omtec Inc. from Ontario (Deligio 2010). To produce the component, wheat straw was gathered and processed by Omtec; the straw was then delivered to A. Schulman for compounding into a resin; and finally, the storage bin component was formed by International Automotive Components Group (IAC).

Figure 10: Wheat Straw/Polypropylene Storage Bin and Cover Liner for the 2010 Ford Flex

Source: Ford

Universities

In 2004, the Ontario Ministry of Agriculture, Food and Rural Affairs awarded a grant to the University of Waterloo (McIntosh 2010) to conduct research and development that would promote the use of bio-based filler materials in automotive applications (Schut 2010). The work under the government grant led to the development of the wheat straw composite that was proposed to Ford in May 2008 (Ontario 2010) by the University of Waterloo, as part of the Ontario BioCar Initiative. Ford was the only automaker member of the Ontario BioCar Initiative at the time, which is why Ford was targeted specifically for the project. The Ontario BioCar Initiative is a partnership between the automotive industry and the public sector and involves researchers from the Universities of Waterloo, Guelph, Toronto, and Windsor. BioCar is aimed at accelerating the use of biological feedstocks in automotive materials (BioCar 2011).

Omtec

As part of product development, BioCar worked with Omtec Inc., an Ontario wheat straw fiber supplier based in Mississauga. Together, the universities and the supplier developed process controls for the wheat straw fiber supply chain. These controls ensure the consistent supply and quality of wheat straw fiber, which is sourced from local farmers (Schut 2010). Once Omtec has gathered the wheat straw, it goes through a proprietary process that cleans, chops, mills, screens, and dries the fiber, preparing it for compounding (Deligio 2010). Once the wheat straw has been processed, it is sent to A. Schulman in Akron, Ohio for compounding.

A. Schulman

A. Schulman's lab tested formulations of wheat straw powder and wheat straw fiber of various lengths and with various levels of conventional reinforcement materials (Schut 2010). Ultimately, the lab created a composition that complied with typical OEM specifications as well as part application requirements (Schulman 2011). Important standards that had to be met included thermal expansion and degradation, rigidity, moisture absorption, and fogging (Deligio 2010). The material is designed for use in injection molding and can be used in existing machinery and tooling. It is designed to be formed at a lower temperature, which saves energy and reduces cycle time (Schut 2010). Once A. Schulman receives the processed wheat straw from Omtec, the company produces a wheat straw/polypropylene resin through a process called extrusion compounding. The material used in the Ford Flex component is officially called AgriPlas™ BF20H-31 (Schulman 2011).

IAC

Once the Agriplas wheat straw/polypropylene resin is compounded by A. Schulman, it is sent to IAC in Strasburg, Virginia, so it can be injection-molded into the bin component (Deligio 2010). IAC was able to begin using AgriPlas in its injection molding presses within two months of beginning preparations (Miel 2009). Once IAC finished molding the bin component, it is sent back to Ontario where Ford installs it in Ford Flex vehicles at its Oakville assembly plant.

Ford

Less than 18 months after the University of Windsor made the initial proposal to Ford's Biomaterials Group, the wheat straw-reinforced plastic was approved for the 2010 Ford Flex (Deligio 2010). The idea to use wheat straw as a reinforcement fiber in a component had been presented to Ford by Dr. Leonardo Simon of the University of Waterloo. Ford had been involved with testing of wheat straw provided by the University of Waterloo early on in the commercialization process. As a member of the BioCar Initiative, Ford worked closely with A. Schulman and the University of Waterloo throughout the process.

Benefits

Compared to other compounds tested in the vetting process, the wheat straw compounds performed similarly, but were dramatically lower in weight (Schut 2010). Compared to the conventional alternative, the wheat straw fiber-reinforced bin is 10 percent lighter (Miel 2009). The material is also recyclable and can easily be ground up and reformed at the end of the vehicle’s life (McIntosh 2010). Ford estimates that using wheat straw in place of resin in the bin will reduce annual petroleum consumption by 20,000 pounds and carbon dioxide emissions by 30,000 pounds (Ford Sustainability Report 2009/2010).

Challenges

Initial challenges involved preparing the wheat straw for compounding. When wheat straw is harvested, farm machinery cuts it into small pieces, but the straw must be ground into much finer pieces in order to add it to plastic (McIntosh 2010). In order to successfully commercialize the bio-based composite, it was important that the wheat straw processing could be done cost effectively; otherwise, the material as a whole would not be cost competitive. Another challenge was ensuring the proper temperature range could be met using already existing machinery. In order to mold the new compound into the form of the bin component, it had to be warm, however if the material got too hot, the straw would begin to react and the material would be unsuitable for use in the bin.

Future

Ford is evaluating other applications for wheat straw fiber-reinforced plastic, due to its lighter weight and greater stiffness (Deligio 2010). Applications being considered include other bins and trays, interior air registers, door panels, and armrests (Ford Sustainability Report 2009/2010). A. Schulman is also considering other applications for the material—in the automotive industry and other industries. Future uses could include under-the-hood applications (Schulman 2009).

Case Study 2: Bio-Based Material Commercialization Fund at the Ontario BioAuto Council

The Ontario BioAuto Council is a non-profit organization that was started by automotive parts suppliers in 2007 with a $6 million grant from the government of Ontario (Crawford 2011). The group is working to bring together the agriculture, forestry, chemical, plastics, manufacturing, automotive parts, and automotive manufacturing industries to create a supply chain for the production of bio-based materials and chemicals (BioAuto Council 2011).

Though it is an industry-led organization, the Ontario BioAuto Council has its roots in the BioCar Initiative, a research partnership. In 2004, a multi-institutional proposal was put forward involving four Ontario universities (University of Toronto, University of Guelph, University of Waterloo, and University of Windsor). Researchers at the universities are working with industry partners to develop renewable materials to replace conventional materials in automotive parts and components. Their work is aimed at reducing cost, increasing functionality, and improving performance of bio-based materials (Ontario 2007). The initiative draws its funds from government, industry, and the universities themselves—with each of the three groups contributing $6 million (Sain 2011).

The BioAuto Council was developed a few years after the BioCar Initiative began, because there was a gap between research on bio-based materials and their commercialization. There was still too much risk involved with bio-based material innovations for companies to make large investments. A group of automotive suppliers approached the government of Ontario to request funding for the Ontario BioAuto Council, which would assist in the commercialization of bio-based material innovations.

The Ontario BioAuto Council's membership includes large Canadian auto parts companies and has expanded to include foreign members from industrial biotechnology, chemical, and agri-business companies interested in partnering with Ontario's manufacturing sector. The Council works with leading universities and research centers in Ontario to promote commercialization partnerships (BioAuto Council 2011).

Ontario BioAuto Council Investment Fund

Originally the BioAuto Council focused on the development and demonstration of bio-based materials in the automotive industry, which was largely driven through its investment fund. Of the $6 million that was given to the BioAuto Council, $3.5 million was used to create an investment fund (Crawford 2011). By providing grants to companies interested in commercializing bio-based products and processes, the fund helps to diminish investment risks (BioAuto Council 2011). The commercialization fund was designed to help overcome the lack of funding available to technologies beyond the initial research stage. Universities fund basic research into bio-based materials and private investors—such as companies and venture capital firms—invest in production of these materials. Frequently, there is a gap between these two funding sources—where development is too far along to be supported by research funding, but the risk is still too high for investors to consider financing further development. This problem is sometimes called “The Valley of Death,” and can result in stalled development of promising new technologies (Mid-Michigan Bio-Alliance 2011).

The fund accepted proposals from applicants, which were circulated for internal review, and passed onto a committee for additional review. Proposals requiring further due diligence were given to a third party service provider, who provided recommendations to the committee where the proposals received a second review. Proposals receiving approval from the committee were submitted to the Board of Directors for final approval. Applicants were then informed of the Board’s decision and, in cases where the proposal was approved, the funding contract was then negotiated (BioAuto Council 2007). Currently all of the money in the fund has been allocated, though the fund could be reloaded and start awarding grants again.

Several automotive supplier projects were initially funded through this process, including grants to Canadian General-Tower, GreenCore Composites, Woodbridge Group, and Magna. As the investment process continued, the Council realized that industries commercializing bio-based materials were all linked, and developing the bio-based materials market could require making investments outside the automotive industry. The BioAuto Council expanded the scope of the fund and made grants to Valle Foam and Carpenter Canada. The following sections describe the work done on the four automotive projects which received grants.

Canadian General-Tower

Canadian General-Tower (CGT) is the top supplier of flexible interior trim coverstock (used in seating, door panels, steering wheel wraps and instrumental panels) to North American automakers (BioAuto Council 2011). With help from a $776,250 grant from the Ontario BioAuto Council, CGT is evaluating two bio-based plasticizers which come from soybeans and castor beans, and can be used in place of conventional petroleum-based plasticizers to make hard PVC plastic soft and flexible so it can be used in automotive interior applications. CGT’s bio-based plasticizing process is called Vehreo. The company could potentially begin using bio-based plasticizers in 90 percent of its products by 2012 (Ontario 2009). Currently Vehreo materials have passed Toyota and other automaker testing and performance specifications. Once the automakers identify a specific component, the approval process can continue to include Vehreo in a vehicle program (BioAuto Council 2011). In Figure 11, Patrick Diebel, CGT's vice president of advanced technology is holding the Vehreo product.

Figure 11: Vehreo from Canadian General-Tower

Source: CGTower 2011

By using Vehreo instead of conventional flexible interior trim coverstock, bio-based oils (soybean and castor oil) are used instead of petroleum, and additional renewable sources (soy and corn protein) are used in the top finish. Because Vehreo uses recycled polyethylene terephthalate (PET) from water and soft drink bottles, the product will also use 55 percent less virgin polyester fibers. The material has a similar look and feel compared to leather and other traditional coverstock and is safer because there are no phthalates (BioAuto Council 2011).

GreenCore Composites

GreenCore was founded in 2005 as a spin-off company from the University of Toronto (Ontario 2009) and was created because researchers at the University of Toronto could not find an existing supplier that could meet their needs to produce the natural fiber reinforced resins they were developing (Sain 2011). GreenCore specializes in advanced natural fiber reinforced thermoplastic materials and has its own manufacturing facilities in Mississauga, Ontario (BioAuto Council 2011). The Ontario BioAuto Council provided a $755,000 grant to help GreenCore refine its production process, improve the products, and support the adoption by industrial customers (Ontario 2009). Figure 12 shows the natural fiber reinforced resin beads produced by GreenCore. GreenCore products are currently in trials with several automotive tier one suppliers and automakers (BioAuto Council 2011).

Figure 12: GreenCore Natural Fiber Reinforced Composites

Source: GreenCore 2011

By using the natural fiber reinforced resins produced by GreenCore, 40 percent of synthetic polymers can be replaced by natural fiber compounds and all glass fibers can be replaced with wood fibers. The resulting material is approximately 20 percent lighter, has greater recyclability, causes less wear and tear on production equipment, and is less expensive as compared to conventional glass fiber reinforced materials (BioAuto Council 2011).

Woodbridge Group

The Woodbridge Group has designed bio-based foams using plant seed oils rather than petroleum (Ontario 2009); these foams are already in production for vehicles. The Woodbridge Group's foam is used in components such as seat cushions, head restraints and arm rests. The BioAuto Council awarded Woodbridge a $1,000,000 grant to develop the Stratas™ Bioheadliner composite. The bio-based headliner is thinner and lighter than a conventional headliner and it also has unique sound absorption properties. In addition to being composed of bio-based foam, it also replaces conventional glass fibers with natural fibers. The bio-based headliner is now in production in several Ford, GM and other automaker vehicles (BioAuto Council 2011). Figure 13 shows the Stratas automotive headliner.

Figure 13: Woodbridge Stratas Headliner

Source: Woodbridge 2011

Woodbridge's bio-based headliner uses 90 percent less toxic chemicals in production and contains 10 percent less glass fiber. It is currently the lightest bio-based headliner available and is 40 percent lighter than conventional headliners. In addition, it has a higher stiffness and strength to weight, is thinner, and has similar acoustic performance. Production processes use less energy and reduce the release of volatile organic compounds (BioAuto Council 2011).

Magna

Magna Exteriors & Interiors is a large manufacturer with 10 production plants in Ontario that produce parts primarily made of plastic—such as bumper systems, interior trim and door panels. With a $500,000 grant from the Ontario BioAuto Council, Magna is developing CellForm™, a loadfloor that uses a 100% recycled cardboard honeycomb core, sandwiched between layers of soy-based polyurethane composite with natural fiber reinforcement (BioAuto Council 2011). The load floor is lighter than a conventional load floor and is designed for use in sport utility vehicles, vans, and cross-over vehicles (Crawford 2009). Currently loadfloors with a recycled cardboard honeycomb core are in production for various automakers (BioAuto Council 2011).

Magna's loadfloor reduces petroleum-based polyol by 50 percent and is 50 percent lighter than conventional loadfloors but has greater strength. Because no supports are required for the loadfloor, it also allows for more cargo space (BioAuto Council 2011).

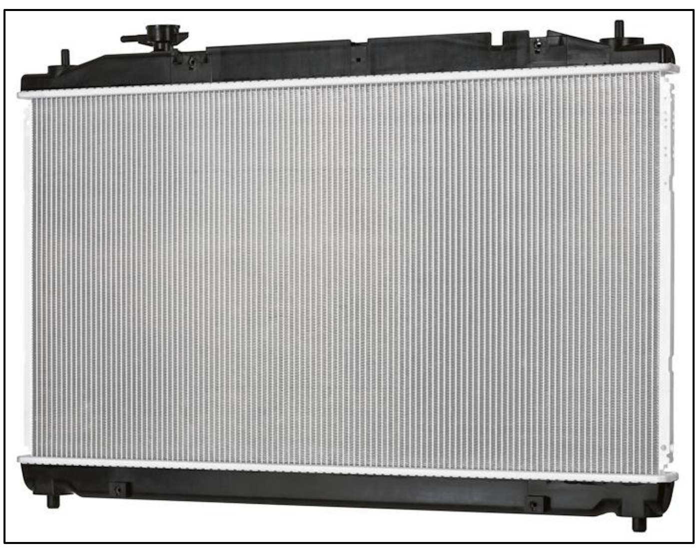
Case Study 3: Castor Oil Based Nylon in the Radiator End Tank of the Toyota Camry

Denso and DuPont have a decades-long history of working together to develop advanced system materials. Several years ago, DuPont assisted Denso in research that allowed Denso to use recycled nylon in its radiator end tanks; more recent work has resulted in the development of a bio-based version of the same component.

Material and Component

Denso engineering and DuPont R&D have jointly developed a new bio-based material derived from the castor bean plant; the material contains 40 percent renewable content by weight and is a nylon resin officially known as Zytel® 610 (DuPont 2009). Its first commercial application was in an automotive radiator end tank produced by Denso for use in the Toyota Camry (DuPont 2009). Figure 14 shows the radiator end tank. The radiator end tank is the first under-the-hood mechanical component application of DuPont renewably-sourced plastic. The development of this material is impressive, because it meets the requirements of the hot, chemically aggressive underhood operating environment (DuPont 2009). Collaboration was the key to the development of this material and application; shared goals, objectives, and clear timelines were essential elements that allowed the program to progress (DuPont 2009).

Figure 14: Denso Radiator End Tank Using Bio-Based Zytel



Source: DuPont 2009

Early Work

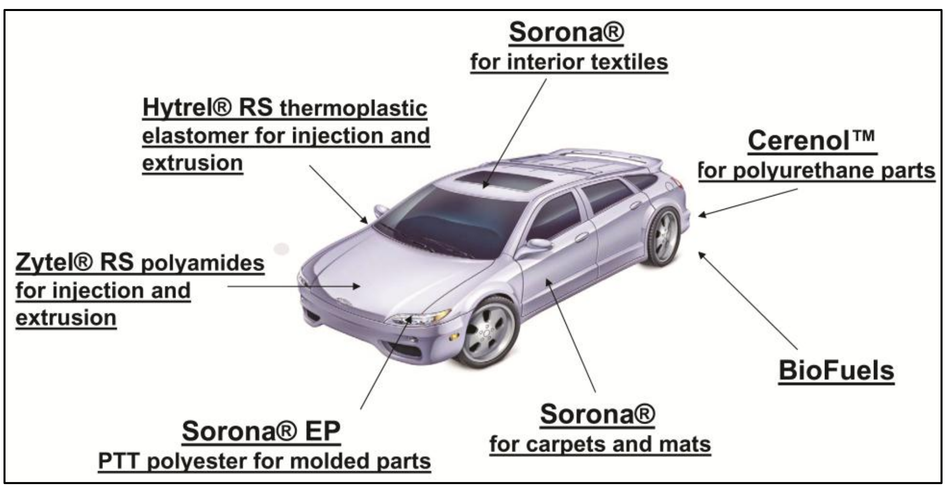
Denso and DuPont have been working together on advanced system materials development projects for more than 25 years (DuPont 2006). DuPont and Denso created a joint development program to help meet the European Union's "End of Life Vehicles" directive. As part of the development program, researchers designed and tested a prototype automotive radiator end tank that used glass-reinforced nylon recovered from post-consumer radiator end tanks.

Tests on the component included high-temperature creep, high-pressure cycling, vibration, and low-temperature impact; results indicated that the component made from recycled materials performed similarly to the conventional component. In 2005 the SAE Arch T. Colwell Merit Award was given to researchers in the United States, Canada, and Japan for a technical paper titled “Application of Nylon Composite Recycle Technology to Automotive Parts” (DuPont 2005). Following this work, Denso and DuPont have continued working together to improve the radiator end tank component (Mundomaterial 2009).

DuPont

DuPont has already introduced several bio-based materials; Figure 15 displays various bio-based materials produced by DuPont and potential application areas in vehicles. DuPont pursued the use of a renewably-sourced nylon resin for the end tank component because DuPont had already been supplying Denso with petroleum-based nylon for radiator end tanks and knew that switching to a bio-based nylon could be potentially beneficial for both companies.

Figure 15: Renewable Materials from DuPont



Source: Bell and Szanto 2010

The Zytel nylon resin was tested to ensure that it met requirements for heat resistance, durability, and road salt resistance; attributes that are challenging to achieve, especially in bio-based resins with significant renewable content (DuPont 2009). The specific application is in a challenging environment, because the material is in full contact with the coolant and may also come in contact with oils. Because of this challenging environment, the material had to have very good chemical and temperature resistance and be able to withstand great pressures.

The nylon resin is castor oil-based, created with castor beans from India, which are converted into sebacic acid in China. The sebacic acid is brought to the United States, where it is converted into the Zytel resin at a DuPont manufacturing plant in West Virginia.

Toyota

Production of the radiator component began in spring 2009 (DuPont 2009) and premiered in the 2010 Toyota Camry in the fall of 2009 (DuPont 2011a). Originally, the end tank was only used in Camry models produced in Japan, but it is now being used in several car lines, and Toyota will use the renewably-sourced component in its U.S.-built vehicles beginning in 2012.

Benefits

The plastics used in the final end tank design were less expensive than conventional alternatives. This bio-based component is a real world example of using bio-based materials to achieve better performance at lower cost, while making environmentally sustainable decisions (Bell and Szanto 2010).

Future

For their joint work on the renewably-sourced radiator end tank, DuPont and Denso Corporation received the "Extraordinary Encouragement Award for Science-Based Innovation" at the 2011 Chunichi Industry Awards ceremony (DuPont 2011a). DuPont also won Denso's "Innovative Technology of the Year" award for the radiator work (Bell and Szanto 2010). Both DuPont and Denso have announced intentions to use the material in a wide range of products (Bell and Szanto 2010 and DuPont 2009).

Other applications for Zytel beyond the radiator end tank could include: fuel lines and tubing, coolant pipes, fuel connectors, and pneumatic tubes. Already Fiat has approved DuPont Zytel resin for use in fuel lines for diesel engines in several of its vehicles. Among these models are the Fiat 500, Panda, and Punto; Lancia Ypsilon and Delta; and Alfa Rameo MiTo and Giulietta. Hutchinson, the fuel line supplier, is exploring the use of DuPont's Zytel in other fuel system applications for other automakers (Miel 2011).

ROADMAP FOR INCREASED COMMERCIALIZATION

This section outlines past approaches to commercialization of bio-based materials in automotive applications and provides suggestions on how to improve commercialization success in the future. CAR's research and meetings with representatives from automakers, suppliers, universities, and associations identified several key factors affecting commercialization including: allocation of risks and rewards among stakeholders, development of supply chains and market demand, and the role of federal, state, and local government in promoting commercialization.

Expanded use of bio-based materials in automobiles can benefit regional farmers, material suppliers, automotive component suppliers, automakers, and society in general. There are, however, a number of barriers to commercialization of new bio-based materials in automotive components, including issues with cost and performance. Overcoming these barriers requires effective advocates in industry, government, universities, and associations to advance automotive development and deployment of bio-based materials.

Bio-based automotive components face many adoption challenges and must meet the same specifications of components made with conventional materials but at a lower or equivalent cost. Sufficient demand must exist to support reasonable economies of scale and development of bio-based material supply chains. Effective business planning and cooperation among stakeholders are essential to success; otherwise, the commercialization process may be stalled due to the many complications along the way, such as meeting specifications and securing a supply base.

Successful Approaches

There are numerous approaches to increase commercialization of bio-based materials in automotive components. In general, the commercialization process could benefit from strong stakeholder involvement and the creation of partnerships and institutions to promote the research and institutional support necessary to enhance the state-of-the-art in bio-based parts and components and overcome current barriers to implementation. Advancing commercialization can be done in a number of ways; the following list outlines various methods which have been used to promote the penetration of bio-based materials in automobiles:

- Establishment of automaker and supplier initiatives
- Coordination of work among universities
- Formation of industry and university partnerships
- Development of cost sharing and matching funds arrangements
- Foundation of commercialization organizations

- Networking among stakeholders
- Creation of knowledge and industry clusters

The methods listed above do not represent independent pathways to commercialization; rather, these initiatives demonstrate collaborative ways to enhance the commercialization environment for bio-based automotive components. The synergies between these aspects can be seen in the previous case studies, which involved several of these initiatives throughout the various stages of the commercialization process.

Many automakers and suppliers are already working on bringing bio-based components to market. For instance, Ford has established a department specifically to conduct work on bio-based materials and has committed to purchasing certain bio-based components for its vehicles. Companies supplying components or materials have dedicated significant resources to developing and testing their products. Strong automaker initiatives and commitments to use bio-based materials can provide the certainty suppliers need to make investments in bio-based material and component production.

Universities play a large role in basic research in bio-based materials, and regional industries can benefit from coordinated university programs that leverage the academic resources of a region to address specific issues. In addition to coordinating universities with each other, encouraging universities and industry to work together can provide academic researchers greater understanding of business, while directing research towards practical applications that are valuable to industry partners. This strategy is frequently employed in Canada and has produced university-industry partnerships such as the Ontario BioCar Initiative and AUTO21.

Commercialization organizations play a vital role in bridging the gap between university research and bringing products to market. These organizations can be quite diverse, ranging from government programs and non-profit groups to for-profit businesses that take university research and move it through the pilot stage. These organizations can include incubators that offer small start-ups space and equipment to test and market their products or establish commercialization funds such as the one set up by the Ontario BioAuto Council.

Networking among the various stakeholder organizations—such as automakers, suppliers, economic development organizations, universities, and government agencies—is instrumental to creating an environment conducive to bio-based product commercialization. By connecting the various stakeholders, knowledge and industry clusters can be created, supply chains can be developed, partnerships explored, and advocacy networks can be strengthened. With greater understanding of the bio-based materials landscape, stakeholders can work together to make these products commercially viable.

Lessons Learned from Case Studies

Three case studies are documented in this report: the wheat straw fiber-reinforced composite used in a storage bin of the Ford Flex, the bio-based material commercialization fund at the Ontario BioAuto Council, and castor oil-based nylon used to manufacture the radiator end tank of the Toyota Camry. These case studies provide a wealth of knowledge relating to the commercialization of bio-based materials in automotive components. Lessons that can be drawn from the cases include:

- Involving industry in research consortiums,
- Moving technology beyond university research into the pilot stage,
- Partnering among companies along the supply chain, and
- Implementing bio-based materials beyond initial applications.

The Ford and BioAuto Council case studies speak to the importance of automaker and supplier involvement in university research consortiums. Because of Ford's involvement in the BioCar Initiative, the company was able to connect with the university researchers, and implement the wheat straw reinforced composite they had been developing. In the Ford case, an existing supplier, A. Schulman, was able to create a new product line to sell to automakers as a result of its involvement in the research consortium; in the BioAuto Council case, a new supplier, GreenCore Composites, was formed in response to the resin needs created by work done under the BioCar Initiative.

Similarly, both the Ford and the BioAuto Council case studies highlight examples of moving bio-based materials technology beyond research and development and into implementation in commercial products. New bio-based materials and processing technologies that are researched in universities eventually face the challenge of overcoming "The Valley of Death," which is the period when development of technology is too far along to be supported by research funding but still too risky for investors to consider financing further development. This creates a gap in funding for further development (Mid-Michigan Bio-Alliance 2011). In the Ford case, involvement of several partners and shared risk along the supply chain allowed the project to move forward to successful commercialization. In the BioAuto Council case, the creation of the commercialization fund allowed individual companies to significantly lower the risk of investing in bio-based materials technology. As a result, several companies now have products that are either already on the market or are nearly commercialized.

In both the Ford and Toyota case studies, partnerships along the supply chain were important to development and implementation of bio-based materials in automotive components. These partnerships can involve automakers, system suppliers, material processors, and material suppliers. In the Ford case, the University of Waterloo and the BioCar Initiative brought together Omtec, the company responsible for supplying and processing the wheat straw; A. Schulman, the resin compounder; and Ford, the automaker, to organize the development of the wheat straw fiber-reinforced composite for the Ford Flex bin. Working together, these organizations were able to successfully implement the new material over a relatively short period of time. In the Toyota case, DuPont, the material supplier, had already established a working relationship with Denso, the material processor and system supplier. DuPont had been previously involved with Denso in jointly researching the use of a nylon composite for radiator end tanks and was the supplier for the nylon already used by Denso for that component. Because of this relationship, DuPont was able to promote the development of a bio-based nylon to replace the conventional nylon. The two companies went on to jointly develop the bio-based end tank component that is now being used in several Toyota models.

The Ford and Toyota cases highlight the strategy of debuting new bio-based materials in low volume applications and then expanding the use of the materials. Ford is currently looking at other applications for the wheat straw fiber-reinforced composite in its vehicles. A. Schulman is also examining other applications for the material, and Cooper Standard is using the material from A. Schulman to make interior seals. The radiator component that Denso made for Toyota debuted in the Camry, but has since been deployed on several models produced in Asia and will soon be used in vehicles produced in North America. In addition, the bio-based nylon that DuPont supplied for the end tank is being used to create diesel fuel lines for Fiat vehicles.

Recommendations to Overcome Obstacles

After reviewing the literature and having discussions with representatives from various organizations, it has become apparent that increasing volumes of bio-based materials as well as bio-based parts and components is key to making bio-based materials viable in automobiles. Large volumes allow for price competition as multiple suppliers emerge, and higher demand for bio-based materials allows producers to reach economies of scale, lowering production costs. In addition to economic considerations, in exterior and under-the-hood applications bio-based materials suffer from shortcomings in technical properties such as rigidity, heat and chemical resistance, and water absorption. Additional research and development as well as pilot and early deployment work may be needed before many of these challenging applications can take advantage of bio-based materials. By using some of the strategies outlined in the previous two subsections, various organizations can work together to promote wider penetration of bio-based materials in vehicles and support further research and development into bio-based materials and applications which still have technical challenges to overcome.

Future Work

While this report provides a solid foundation on the status of the use of bio-based materials in automotive parts and components, additional inquiry is needed to understand the current and potential size of the bio-based material market in the automotive sector. Further research could examine the realistic potential of the market and investigate the maturity curve for bio-based technologies in automobiles. A supplemental study could also address in detail the role of the government in motivating the bio-based automotive market. The study could make recommendations to strategically support the development of the bio-based materials industry specific to businesses and other organizations in the Great Lakes region. Future work could also include the establishment of an automotive bio-based products network in Great Lakes region. Such a network could facilitate relationships and business development among interested stakeholders and cultivate the bio-based automotive components market.

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APPENDIX A: GLOSSARY

Terminology	Definition
Abaca	Grown as a commercial crop in the Philippines, Ecuador, and Costa Rica, being harvested for its fiber
Acrylate	Common monomers in polymer plastics
Amylose	A linear polymer made up of D-glucose units
Bagasse	The residual matter created after sugarcane or sorghum stalks are crushed to extract their juice
Bast	Plant fiber that is used in many textile applications
Bio-based PA 10	A bio-based polymer based on 100% renewable materials and sebacic acid
Bio-based PA 10-10	A polymer derived from castor oil feedstocks and has automotive applications such as fuel lines, engine mounts, and transmission parts
Bio-based PA 6-10	A bio-based polymer reinforced with glass fiber and mineral substances that has automotive applications
Bio-based PE	Bio-based monomer (ethylene) obtained from ethanol which is produced by fermentation of sugar
Bio-based PEBA	Made from polyamide 11 , which is made out of castor oil, and is used as an additive or blend for the production of polymers or rubbers
Bio-based PP	A bio-based version of polypropylene, a thermoplastic polymer used in a wide variety of applications including packaging, textiles
Bio-based PVC	A bio-based version of polyvinyl chloride
Bio-based TPU	Plant based thermoplastic polyurethane made from renewable-sourced materials and recyclable materials
Bio-PET	A type of polyethylene that is made by replacing the monoethylene glycol with a biological raw material derived from sugar cane
Carbon fixation	A process that converts gaseous carbon dioxide into a solid compound
Cassava	A woody shrub cultivated as an annual crop and serves as a major source of carbohydrates
Castor Bean	A seed from the castor oil plant, which is actually not a true bean and is cultivated for its oils
Castor Oil	A vegetable oil obtained from the castor bean
Cellulose Based Polymers	A complex carbohydrate that is the basic structural component of the plant cell wall
Co-polyesters	Forms when modifications are made to polyesters, which are combinations of diacids and diols
Flax	A plant grown both for its seeds and fibers used to make fabric, dye, paper, medicines, fishing nets, hair gels, and soap
Glycoside Hydrolases	Common enzymes that assist in the degradation of biomass such as cellulose and hemicellulose
Goldenrod	A genus of a flowering plant to make natural latex
Hemicellulose	Any of several heteropolymers present along with cellulose in almost all plant cell walls
Hemp	A fiber heavily used for its industrial applications including the production of paper, biodegradable plastics, health foods, and fuel
High-density polyethylene (HDPE)	A polyethylene thermoplastic made from petroleum
Hyaluronan	A type of acid with applications in medical, cosmetics, equine, and etymology

Terminology	Definition
Ingeo	The trademark name for NatureWorks LLC's synthetic fiber made from corn; it is a resin for film and textiles applications
Isosorbide	A heterocyclic compound derived from glucose and is thus a bio-based feedstock
Jatropha	A genus that is used for biodiesel production
Jute	One of the most heavily produced vegetable fibers in the world
Kenaf	Fibers used to make paper and other applications
Linear low-density polyethylene (LLDOE)	A type of polyethylene used in applications such as plastic bags, plastic wrap, toys, and pipes
Monomer	An atom or a small molecule that may bind chemically to other monomers to form a polymer
Olefin	In organic chemistry, an olefin is an unsaturated chemical compound containing at least one carbon-to-carbon double bond
PA11, Polyamide 11	A biopolymer derived from natural oil with many applications such automotive fuel lines, and pneumatic airbrake tubing
Paclitaxel	A mitotic inhibitor used in cancer chemotherapy
PBS	A type of polyester for automotive
PCL, Polycaprolactone	A biodegradable polyester
Petroleum Resins	A byproduct from cracked and distilled petroleum streams with applications for adhesives, printing inks, and surface coatings
PGA, Polyglycolic Acid	A biodegradable, thermoplastic polymer that has been traditionally used in biomedical applications
PHA, Polyhydroxyalkanoate	A biopolymer that is made by bacteria and uses renewable raw material such as sugar from crop
PHB, Polyhydroxybutyrate	A high molecular weight polyester and is a biodegradable thermoplastic
PHBV, Poly-3-hydroxy butyrate-co-valerate	A biopolymer resin derived from 100% annually renewable sources (starch is one)
PLA , Polylactic acid	A thermoplastic polyester derived from renewable resources such as corn starch, tapioca products, and sugarcanes
PLA Blends	Polymers made from PLA but blended with other polymers such as PP, and PET
PLGA, Poly-lactic-co-glycolic Acid	A copolymer used in various therapeutic devices
Polyethylene (PE)	A thermoplastic polymer
Polyethylene terephthalate (PET)	A thermoplastic polymer resin used in synthetic fibers; beverage, food and other liquid containers; and engineering resins
Polyhydroxy-butyrate	A material similar to conventional polyester that is produced by microorganisms
Polylactic Acid (PLA)	A thermoplastic aliphatic polyester derived from renewable resources
Polymer	A large molecule that refers to plastics, it comprises of both natural and synthetic materials with a wide variety of properties and applications
Polyolefins	A thermoplastic polymer with a wide array of applications including automotive, wire & cables, and optical
Polypropylene (PP)	A thermoplastic polymer used in a wide variety of applications including packaging, and automotive components
Polyvinyl Chloride (PVC)	A thermoplastic polymer
Potassium Acetate	A potassium salt of acetic acid that can be used for applications such as airport runways

Terminology	Definition
PPT	A type of automotive plastic
Ramie	A bast fiber principally used for fabric production
Rapeseed	A bright yellow flower used for oil production
Resin	Valued for its chemical properties and production of varnishes, adhesives, food glazing agents, incense, and perfume
Sisal	An agave that contains a fiber used in making twine, rope and also dartboards
Soybean	A species of legume grown for its edible bean which has numerous uses
Starch Based Polymers and Blends	Biodegradable polymers with a broad range of applications including biomedical and environmental
Suberin	A waxy substance found in higher plants such as cork
Thermoplastic	Molecules that are supplied in the form of pellets, which contain additives to enhance processing of a finished product
Thermoplastic polyurethane (TPU)	A polyurethane plastic that is extensively used in many applications due to its useful properties, including resistance to oil
Thermoset	Plastics that can be supplied in liquid form or as a partially polymerized solid molding powder

APPENDIX B: ACRONYMS

Acronym	Phrase	Explanation
ADM	Archer Daniels Midland	A large agricultural supplier
ALSA	Advanced Laser Surface Analyzer	Tool used to measure surface quality
ASTM	American Society for Testing and Materials	A standards organization
CAR	Center for Automotive Research	A non-profit automotive research group
CGT	Canadian General-Tower	An automotive supplier
CIRAS	Center for Industrial Research and Service	Institution at Iowa State University
DOE	U.S. Department of Energy	A U.S. federal agency
EU	European Union	A political and economic union of several European countries
HDPE	High Density Polyethylene	A polyethylene thermoplastic made from petroleum
IAC	International Automotive Components	An automotive supplier
ISO	Isocyanates	Chemicals that are widely used in the manufacture of fibers and paints used in the automobile applications
ISO	International Organization for Standardization	A standards organization
LCA	Life Cycle Assessment	An environmental and economic metric used to inform decisions
MEG	Mono-ethylene Glycol	An organic compound widely used as an automotive antifreeze
mpg	Mile Per Gallon	A measure of fuel economy
MSPC	Michigan Soybean Promotion Committee	A fund to promote the soybean industry
OBIC	Ohio BioProducts Innovation Center	An institution at Ohio State University
ORNL	Oak Ridge National Labs	A national research laboratory
PA	Polyamide	A polymer that occurs both naturally and artificially, examples being proteins, such as wool and silk
PCU	Polycaprolactone	A biodegradable polyester
PE	Polyethylene	A widely used plastic, with a primary use in plastic bags, plastic films, and other types packaging
PEBA	Polyether block amide	A high performance thermoplastic used to replace common elastomers such as thermoplastic polyurethanes and silicones
PET	Polyethylene Terephthalate	A thermoplastic polymer resin used in synthetic fibers, containers, and engineering resins
PGA	Polyglycolic Acid	A biodegradable, thermoplastic polymer
PHA	Polyhydroxyalkanoate	A type of polyester that is produced in nature by bacterial fermentation of sugar or lipids
PHB	Polyhydroxybutyrate	A polymer produced by microorganisms
PHBV	Poly-3-hydroxy butyrate-co-valerate	A bio-polymer resin
PLA	Polylactic Acid	A thermoplastic polyester derived from renewable resources, such as corn starch

Acronym	Phrase	Explanation
PLGA	Poly-lactic-co-glycolic Acid	A copolymer which is used in many applications such as therapeutic devices
PP	Polypropylene	A thermoplastic polymer used in a wide variety of applications including packaging and automotive components
PVC	Polyvinyl Chloride	A thermoplastic polymer that is widely used in construction because of its durability and reasonable price
SAE	Society of Automotive Engineers	A professional organization
SEDS	Sustainability and Economic Development Strategies	A research group within CAR
SMC	Sheet Molding Compound	A fiber-reinforced polyester material primarily used in compression molding
SQ	Surface quality	Important property of a material
TPU	Thermoplastic polyurethane	A polyurethane plastic that is extensively used in many applications due to its useful properties, including resistance to oil
UPR	Unsaturated Polyester Resins	Used in the production of fiber-reinforced plastics for various applications
USDA	U.S. Department of Agriculture	A U.S. federal agency
VOC	Volatile Organic Compounds	Organic chemicals that are often a residual from the production of biomaterials and can be harmful to humans and the environment
WPC	Wood-Plastic Composite	Any composites that contain plant fiber and thermosets or thermoplastics

APPENDIX C: SELECT AUTOMAKER PRODUCTS CONTAINING BIO-BASED MATERIALS

Company	Brand	Model(s)	Feedstock	Material	Application
BMW	BMW	7-Series	Sisal	Acrylic polymer	Interior door panel
Chrysler	Chrysler	Sebring	Kenaf, hemp	Polypropylene	Interior door panel
Daimler	Mercedes-Benz	A-Class	Abaca/banana	Composite material	Underbody panels
Daimler	Mercedes-Benz	A-Class	Flax	Composite material	Seatbacks
Daimler	Mercedes-Benz	A-Class	Natural fibers	Composite material	Spare tire cover
Daimler	Mercedes-Benz	C- and A-Class	Flax	Polyethylene	Engine cover
Daimler	Mercedes-Benz	C- and A-Class	Flax	Polyethylene	Transmission cover
Daimler	Mercedes-Benz	C- and A-Class	Flax	Polyethylene	Underbody panels
Daimler	Mercedes-Benz	C-Class	Sisal, cotton	N/A	Rear panel shelf
Daimler	Mercedes-Benz	E-Class	Flax, sisal	Epoxy resin matrix	Interior door panel
Daimler	Mercedes-Benz	E-Class	Jute	N/A	Interior door panel
Daimler	Mercedes-Benz	S-Class	Hemp, flax, sisal, coconut	N/A	Interior components
Fiat	Alfa Rameo	Giulietta	Castor	Zytel	Fuel line
Fiat	Alfa Rameo	MiTo	Castor	Zytel	Fuel line
Fiat	Fiat	500	Castor	Zytel	Fuel line
Fiat	Fiat	Panda	Castor	Zytel	Fuel line
Fiat	Fiat	Punto	Castor	Zytel	Fuel line
Fiat	Lancia	Delta	Castor	Zytel	Fuel line
Fiat	Lancia	Ypsilon	Castor	Zytel	Fuel line
Ford	Ford	Econoline	Soy	Polyurethane	Foam seating
Ford	Ford	Edge	Soy	Polyurethane	Headliner
Ford	Ford	Escape	Soy	Polyurethane	Foam seating
Ford	Ford	Escape	Soy	Polyurethane	Headliner
Ford	Ford	Expedition	Soy	Polyurethane	Foam seating
Ford	Ford	F-150	Soy	Polyurethane	Foam seating
Ford	Ford	Fiesta	Corn	N/A	Tires
Ford	Ford	Fiesta	Kenaf	Polypropylene	Interior door panel
Ford	Ford	Flex	Soy	Polyurethane	Foam seating
Ford	Ford	Flex	Wheat straw	Polypropylene	Interior storage bins
Ford	Ford	Focus	Castor	Polyurethane	Instrument panel
Ford	Ford	Focus	Kenaf	Polypropylene	Interior door panel
Ford	Ford	Focus	Soy	Polyurethane	Foam seating
Ford	Ford	Focus BEV	Coconut	Polypropylene	Loadfloor
Ford	Ford	Freestar	Wood	Polypropylene	Sliding door inserts
Ford	Ford	Fusion	Soy	Polyurethane	Seating headrests
Ford	Ford	Fusion	Wood	N/A	Trim
Ford	Ford	Model U concept	Soy	Polyurethane	Foam seating, rigid polyurethane tailgate

Company	Brand	Model(s)	Feedstock	Material	Application
Ford	Ford	Mondeo	Kenaf	Polypropylene	Interior door panel
Ford	Ford	Mustang	Soy	Polyurethane	Foam seating
Ford	Ford	Taurus	Soy	Polyurethane	Foam seating
Ford	Ford	Taurus SHO	Wood	N/A	Trim
Ford	Lincoln	Mark LT	Wood	N/A	Trim
Ford	Lincoln	MKS	Soy	Polyurethane	Foam seating
Ford	Lincoln	MKS	Wood	N/A	Trim
Ford	Lincoln	MKX	Soy	Polyurethane	Headliner
Ford	Lincoln	MKX	Wood	N/A	Trim
Ford	Lincoln	MKZ	Renewably sourced	Polyurethane	Console door
Ford	Lincoln	MKZ	Soy	Polyurethane	Seating headrests
Ford	Lincoln	MKZ	Wood	N/A	Trim
Ford	Lincoln	Navigator	Soy	Polyurethane	Foam seating
Ford	Lincoln	Navigator	Wood	N/A	Trim
Ford	Mercury	Mariner	Soy	Polyurethane	Foam seating
General Motors	Cadillac	DeVille	Wood	Polypropylene	Seatbacks
General Motors	Chevrolet	Impala	Flax	Polypropylene	Trim, rear shelf
General Motors	Chevrolet	TrailBlazer	Wood	N/A	Cargo area floor
General Motors	GMC	Envoy	Wood	N/A	Cargo area floor
General Motors	GMC	Terrain	Cotton	Polyester	Acoustic insulator
General Motors	GMC	Terrain	Kenaf	N/A	Ceiling liner
General Motors	Opel	Astra/Vectra	Hemp, kenaf, flax	N/A	Interior door panel
General Motors	Opel	Astra/Vectra	Hemp, kenaf, flax	N/A	Seatbacks
General Motors	Saturn	L300	Kenaf, flax	N/A	Interior door panel, package trays
Honda	Honda	FCX fuel cell concept	Corn	Polypropylene terephthalate	Interior fabric
Honda	Honda	Pilot	Wood	N/A	Floor area parts
Hyundai	Hyundai	"i-flow" concept	Castor	Nylon	Seat frames
Mazda	Mazda	Mazda 5 Hydrogen RE Hybrid	Corn	Polylactic acid	Console, seat fabric
Nissan	Nissan	Leaf	Corn	Sorona	Floor mats
Toyota	Lexus	CT200h	Bamboo	Polyethylene terephthalate	Luggage-compartment, speakers

Company	Brand	Model(s)	Feedstock	Material	Application
Toyota	Lexus	CT200h	Corn	Sorona	Floor mats
Toyota	Lexus	ES300	Kenaf	Polylactic acid	Package shelves
Toyota	Lexus	HS250h	N/a	Bioplastics	Interior components
Toyota	Toyota	"i-unit" and "i-foot" concept	Kenaf	N/A	Body structure
Toyota	Toyota	Brevis	Kenaf	Polypropylene	Interior door panel
Toyota	Toyota	Camry	Castor	Zytel	Radiator end tank
Toyota	Toyota	Celsior (Lexus LS)	Kenaf	Polypropylene	Interior door panel
Toyota	Toyota	ES3 concept	Sweet potatoes, sugar cane	Bioplastics	Interior components
Toyota	Toyota	Harrier (Lexus RX)	Kenaf	Polypropylene	Interior door panel, seatbacks
Toyota	Toyota	Prius	Corn	Sorona EP	Instrument-panel, air-conditioning vent
Toyota	Toyota	Raum	Kenaf, starch	Composite material	Floor mats
Toyota	Toyota	Raum	Kenaf, starch	Composite material	Spare tire cover
Toyota	Toyota	SAI	Corn	Sorona	Ceiling surface skin, sun visor, pillar garnish
Volkswagen	Audi	A2	Flax, sisal	Polyurethane	Interior door panel

APPENDIX D: SELECT AUTOMAKERS INVOLVED WITH BIO-BASED MATERIALS

Organization Name	Address	City	State/Province	Country
BMW	Petuelring 130	Munich	Bavaria	Germany
Chrysler	1000 Chrysler Drive	Auburn Hills	Michigan	USA
Ford	15031 South Commerce Drive	Dearborn	Michigan	USA
General Motors	300 Renaissance Center # L1	Detroit	Michigan	USA
Honda	1919 Torrance Boulevard	Torrance	California	USA
Hyundai	10550 Talbert Avenue	Fountain Valley	California	USA
Kia	111 Peters Canyon Road	Irvine	California	USA
Mazda	1444 McGaw Avenue	Irvine	California	USA
Mercedes	3 Mercedes Drive	Montvale	New Jersey	USA
Mitsubishi	6450 Katella Avenue	Cypress	California	USA
Nissan	One Nissan Way	Franklin	Tennessee	USA
Toyota	19001 South Western Avenue	Torrance	California	USA
Volkswagen	2200 Ferdinand Porsche Drive	Herndon	Virginia	USA

APPENDIX E: SELECT SUPPLIERS INVOLVED WITH BIO-BASED MATERIALS

Organization Name	Address	City	State/Province	Country
A. Schulman	3550 West Market Street	Akron	Ohio	USA
Arkema	900 First Avenue	King of Prussia	Pennsylvania	USA
Ashland Performance Materials	5200 Blazer Parkway	Dublin	Ohio	USA
BASF	1609 Biddle Avenue	Wyandotte	Michigan	USA
Bayer MaterialScience (BMS) LLC	100 Bayer Rd	Pittsburgh	Pennsylvania	USA
Bodycote	SK10 2XF Springwoo Court	Cheshire	Macclesfield	UK
Bosch	38000 Hills Tech Drive	Farmington Hills	Michigan	USA
Braskem SA	8501 Eldorado Business Tower	Sao Paulo	Sao Paulo	Brazil
Bulk Molding Compounds, Inc. (BMCI)	1600 Powis Court	West Chicago	Illinois	USA
Cambridge Industries Inc.	555 Horace Brown Drive	Madison Heights	Michigan	USA
Canadian General-Tower Ltd. (CGT)	52 Middleton Street	Cambridge	Ontario	Canada
Cargill Inc.	12700 Whitewater Drive	Minnetonka	Minnesota	USA
CelluForce	625, avenue du President Kennedy	Montreal	Quebec	Canada
Cereplast	2213 Killion Avenue	Seymour	Indiana	USA
Cooper Standard	39550 Orchard Hill Place	Novi	Michigan	USA
CPI Banini	1700 Wilkie Dr.	Winona	Minnesota	USA
Denso	25614 Gina Court	Novi	Michigan	USA
Dow Chemical Company	2030 Dow Center	Midland	Michigan	USA
Draths Corp.	4055 English Oak Drive	Lansing	Michigan	USA
Dräxlmaier	Landshuter Str. 100	Vilsbiburg	Bavaria	Germany
DSM	Het Overloon 1	Heerlen	Limburg	Netherlands
DuPont	1930 Tremainsville Road	Toledo	Ohio	USA
Durafibre Inc.	4825 Trousdale Dr. Suite 205	Canora	Saskatchewan	Canada
Faurecia Interior Systems	2380 Meijer Drive, Suite B	Troy	Michigan	USA
Federal Mogul	26555 Northwestern Highway	Southfield	Michigan	USA
Filter Media Specification	294 Sunset Rd	Pittsburgh	Pennsylvania	USA
Findlay Industries	4000 Fostoria Road	Findlay	Ohio	USA
FlexForm Technologies	4955 Beck Dr.	Elkhart	Indiana	USA
FP Innovations	570 St.-Jean Blvd.	Pointe-Claire	Quebec	Canada
Green Natural Fibers	3628 Highway 91 N	Snow Hill	North Carolina	USA
GreenCore Composites	642 King Street West #200	Toronto	Ontario	Canada
International Automotive Components	28333 Telegraph Road	Southfield	Michigan	USA

Organization Name	Address	City	State/Province	Country
Johnson Controls (JCI)	5757 N. Green Bay Ave.	Milwaukee	Wisconsin	USA
Lear	21557 S. Telegraph Rd.	Southfield	Michigan	USA
Magna International	337 Magna Drive	Aurora	Ontario	Canada
Merquinsa	915 Johnson Street	North Andover	Massachusetts	USA
Mitsubishi Plastics	1-2-2, Nihonbashihongokucho, Chuo-ku	Tokyo	Tokyo	Japan
Mitsubishi Rayon	shinagawa crystal square, 6-41, konan 1-chome, minato-ku	Tokyo	Tokyo	Japan
Omtec	181 Liberty Street	Marlboro	Massachusetts	USA
Pavaco Products	370 Elgin St.	Brantford	Ontario	Canada
Polyone	33587 Walker Rd.	Avon Lake	Ohio	USA
PPG	One PPG Place	Pittsburgh	Pennsylvania	USA
PTT PLC	555 Vibhavadi Rangsit Road	Chatuchak	Bangkok	Thailand
Quadrant Natural Fiber Composites GmbH	DE-49076 OSNABRÜCK	Niedersachsen	Germany	Germany
Rieter Automotive Systems	N/A	Winterthur	Zurich	Switzerland
Roquette America Inc.	2211 Innovation Drive	Geneva	Illinois	USA
SABIC Innovative Plastics	31220 Oak Creek Drive	Wixom	Michigan	USA
Tata Technologies	41050 W. Eleven Mile Road	Novi	Michigan	USA
The Woodbridge Group	1515 Equity Drive	Troy	Michigan	USA
Valle Foam	4 West Dr.	Brampton	Ohio	USA
Visteon	One Village Center Drive	Van Buren Township	Michigan	USA
Woodbridge Foam	1515 Equity Drive	Troy	Michigan	USA

APPENDIX F: SELECT ASSOCIATIONS INVOLVED WITH BIO-BASED MATERIALS

Organization Name	Address	City	State/Province	Country
AUTO21	754 California Avenue	Windsor	Ontario	Canada
BioAlliance of Mid-Michigan	325 E. Grand River Ave Suite 275	East Lansing	Michigan	USA
Indiana Biobased Products Advisory Commission (Expired June 2008)	101 W. Ohio St., Ste. 1200	Indianapolis	Indiana	USA
Michigan Biopreferred Products Association	9421 Bismark Hwy	Vermontville	Michigan	USA
Michigan Soybean Promotion Committee (Soybean Checkoff)	N/A	Frankenmuth	Michigan	USA
National Corn Growers Association	632 Cepi Drive	Chesterfield	Missouri	USA
Ontario BioAuto Council	100 Stone Road W. Suite 205	Guelph	Ontario	Canada
Ontario BioCar Initiative	50 Stone Road E.	Guelph	Ontario	Canada
PolymerOhio	155 Commerce Park Drive	Westerville	Ohio	USA
SAE International	755 W. Big Beaver, Suite 1600	Troy	Michigan	USA
Sustainable Chemistry Alliance	1086 Modeland Road	Sarnia	Ontario	Canada

APPENDIX G: SELECT UNIVERSITIES INVOLVED WITH BIO-BASED MATERIALS

Organization Name	Address	City	State/Province	Country
Bioproducts Discovery & Development Centre, University of Guelph	50 Stone Road E.	Guelph	Ontario	Canada
Composite Vehicle Research Center (CVRC)	2727 Alliance Drive	Lansing	Michigan	USA
MSU Bioeconomy Institute and Network	238, 232 Administration Building	East Lansing	Michigan	USA
MSU Bioeconomy Network	232 Administration Building	East Lansing	Michigan	USA
MSU Composite Materials and Structures Center	2100 Engineering Building	East Lansing	Michigan	USA
LSU Textile Processing Laboratory	125 Human Ecology Building	Baton Rouge	Louisiana	USA
Ohio BioProducts Innovation Center (OBIC)	152 Howlett Hall, 2001 Fyffe court	Columbus	Ohio	USA
Center for Biocomposites and Biomaterials Processing, University of Toronto	33 Willcocks Street	Toronto	Ontario	Canada
Sao Paulo State University	N/A	Sao Paulo	Sao Paulo	Brazil
Ontario BioCar Initiative	50 Stone rd.	Guelph	Ontario	Canada
University of Windsor	401 Sunset Avenue	Windsor	Ontario	Canada
Waterloo Centre for Automotive Research, University of Waterloo	200 University Avenue West	Waterloo	Ontario	Canada