

# Review of the Applications of Biocomposites in the Automotive Industry

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**The article provides an overview of biocomposite application in the automotives via a documentation of their history, chronology and progressive steps taken to break into the production lines of a number of key auto makers. It offers a detailed analysis of the key factors that have motivated the research and subsequent adoption of biocomposites; taking a peek at the advantages, disadvantages, and challenges experienced in the process. Auto makers and parts suppliers that have been a force behind this campaign, have also been accorded a fair share in the article. Future projection of role of these materials in the industry; with the ideas well dressed in form of bio concept cars caps up the paper. Automotive refers to; passenger cars, sport utility vehicles, vans, trucks, buses, and recreational vehicles. POLYM. COMPOS., 00:000–000, 2016. © 2016 Society of Plastics Engineers**

## INTRODUCTION

Biocomposites comprise one or more phases derived from a biological origin; these may be reinforcements (cotton, hemp, flax, sisal, jute, and kenaf or recycled wood and paper) or organic matrices, for example, polylactic acid (PLA) and soybean resins [1–3]. Use of natural fibers has been in existence for many generations, however, the discovery and subsequent commercialization of synthetics such as glass, aramids, and carbon fibers in early and mid-twentieth century resulted in the reduced preference for natural fibers in a number of applications. This was a time of robust industrial and technological development that required use of highly reliable materials with consistent properties; a test well passed by the newly engineered fibers and somehow failed by the natural fibers as physical and chemical properties had big variations and fluctuations stemming from weather, harvesting methods, transportation, storage, and processing. Conven-

tional fibers and to a bigger extent glass fibers, have been unrivalled as automotive composite reinforcements since their inception in the industry in 1953. General Motors set precedence using them in Chevrolet Corvette [4] where a total of 46 separate glass fiber-reinforced parts made in open molds by hand rolling polyester resins into glass fiber mats were supplied by Molded Fiber Glass Company of Ashtabula, Ohio. These were used in the assembly of a prototype car; after which, a batch of three hundred were made. The reason for this momentous switch from traditional steel and aluminum parts to glass composites was to attain an improved weight reduction, better mechanical properties, and processing efficiency. Ever since, glass fibers' positive attributes; great abundance, low cost, good mechanical properties, and reliable performance have enabled them a place alongside steel in car body building using up to 15% of the world's steel, 25% of the world's glass, and consuming 40% of the annual world oil output. Despite efforts to reduce the car weight, over generations, there has been an overall gradual increase with an example of Audi increasing by 460 kg in weight between 1972 and 2003 [5], thus, the auto designers have to harmonize the changing social demands of greater comfort, better driving performances, and higher safety standards with the environmental requirements. Automotive account for 23% of the total global carbon emissions and pollution during the vehicle's active time stands at around 80% of the total emissions during its life [6, 7], subjecting the environment to a heavy burden of greenhouse gas pollution. With every 10% eliminated from the vehicle's total weight improving the fuel efficiency by up to 7%, and every 1 kg saved on the vehicle weight saving the environment by around 20 kg of carbon dioxide, use of biocomposite materials would have a twofold benefit; lowering the total vehicle weight which would result in increased fuel efficiency. According to Martin Goede et al. [8], 100-kg mass reduction in a car weight could result into a 0.3–0.5 dm<sup>3</sup>/100 km fuel consumption reduction and a 7.5–12.5 g/km

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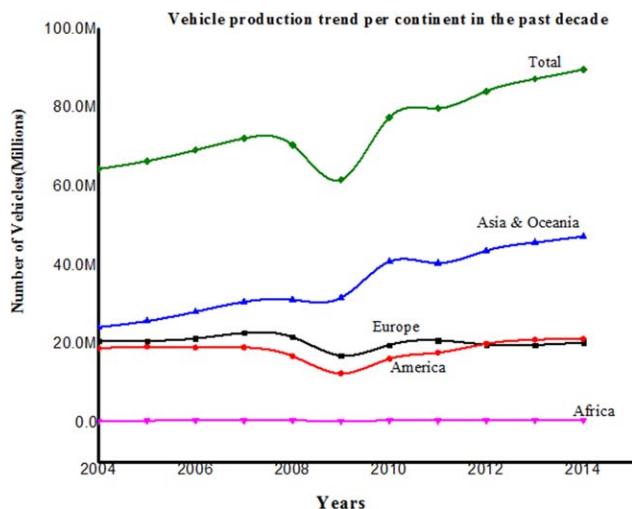


FIG. 1. The trend of the global motor vehicle output/production by continent in the last decade. Data sourced from (OICA) [20]. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

carbon dioxide emission decrease. Hiroshi Kawamoto [9], noted that; in the automobile industry where further global notarization is expected to proceed, making proactive effort to reduce the environmental burden in the total life cycle of the automobiles including development, production, use, disposal, and recycling would be strongly required upon which he called upon the industry stakeholders to embrace the promotion of reduced global carbon dioxide emissions and establishment of a sustainable society. With several vehicles clocking their end of life annually, the industry generates between 8 and 9 million tons of waste of which only about 65–75% is successfully recycled or safely disposed off [10, 11] implying a need to carefully consider the cumulative effect of these residues. Various governments together with environmental bodies are encouraging the use of sustainable and eco-efficient materials via policies targeting waste generation, recycling, and carbon emission targets. The European Union parliament end of life directive of 2,000 targeted a recycling of 85% by weight by the year 2006 and 95% by 2015 [12, 13]. The European Commission and the European Automobiles Manufacturers' Association together, put in place a legislation aimed at reducing CO<sub>2</sub> emission from light vehicles targeting 65% of all the new vehicles sold meeting a 130 g/km carbon dioxide emission mark by 2012, 75% by 2013, 80% by 2014, 100% by 2015 and ultimate, a target of 95 g/km by the year 2020 [14]. Following this, the Japan Automobile Manufacturers Association (JAMA) and Korea Automobile Manufacturers Association (KAMA) set a CO<sub>2</sub> emission target of 140 g CO<sub>2</sub>/km by 2009 for all vehicles sold in Europe [15]. While in the United States, the government is implementing a directive to have a progressive increase in the fuel economy to 54.5 miles per gallon (mpg) for cars and light-duty trucks by the model year 2025 [16]. Besides, the car users would save billions of dollars on

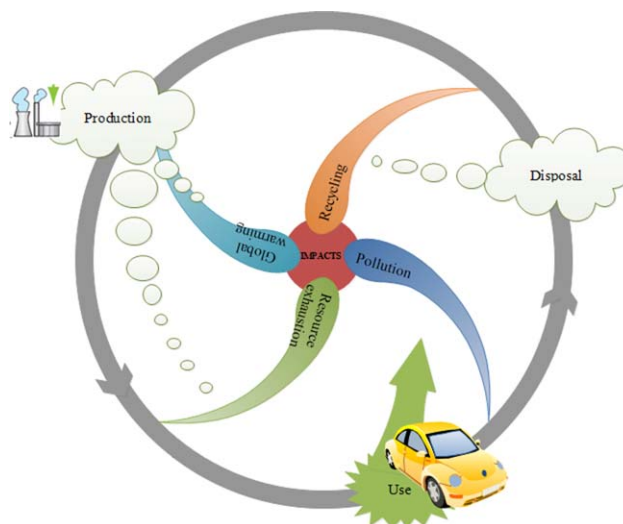


FIG. 2. An illustration of the impact of the automotive production chain on the environment. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

the pump gas with a projected oil consumption reduction of 12 billion barrels. A 2011 report by the center for automotive research (CAR) Michigan [17] estimated the U.S. auto industry to be around \$370 billion then, in that regard, with 75% of the vehicle's energy consumption reportedly associated with its mass [18], reducing the automotive weight by natural fiber composites would not only benefit the environment but also the automotive users as well [19] (Figs. 1 and 2).

## HISTORY OF NATURAL FIBER COMPOSITE RESEARCH AND APPLICATION IN THE AUTOMOBILES

The idea of using bio-based materials in vehicle parts was first pondered by the founder of the Ford Motor company in early 1930s [21]. Inspired by the farmers' plight, Henry Ford sought means of financially empowering them and having soil as the practical source of car parts and fuels seemed feasible. Besides, in a quest for environmentally friendly light-bodied cars [22], these materials offered a promise of weight and emissions regulation. Thus, the Ford motor company undertook an aggressive research into the extensive use of natural fibers in automobiles which climaxed with the unveiling of the T concept car in 1941 [23]. This had a body featuring mostly soy resin-reinforced hemp, sisal, and wheat straw composites this had its weight two thirds that of a regular car with an engine running on hemp oil fuel. The oil abundance at the time and the sudden plunge of the automotive industry into the Second World War came with need for highly mechanized vehicles affecting the progress of this research. The year 1957 saw a major breakthrough for biocomposites in the automotive with the East German built a Trabant car having a monocoque construction with the roof, bootlid, bonnet, wings, and doors

manufactured from a thermosetting phenolic resin reinforced with cotton [24]. In 1982, FIAT introduced wood floor filled door panels in the FIAT punto [25]. Despite these initial trials, practical usage of natural fibers and bio composites in automotive only took off in the late twentieth century when the rate of fossil resource depletion—the biggest force behind the flourish of the industry, began to be more evident. This together with the steady threat of the industry to the environment pushed the stakeholders into considering the extensive application of more fuel efficient, environmentally friendly, lighter, and renewable materials in vehicle assembling [26, 27]. Thus, since 1991, Daimler Benz has been engaged in an intensive research to replace glass fiber reinforcements with natural fibers in some of its auto parts. A subsidiary of Daimler-Benz in Sao Paulo Brazil undertook the “Beleem project” where coconut fibers were used for commercial vehicle parts [3, 28]. A number of other key industry players have equally picked up on the campaign and a lot of progress has been registered both in the laboratories and production as will be extensively explored in the text ahead.

### **THE PROGRESSIVE ROLE PLAYED BY AUTOMAKERS, AUTO SUPPLIERS, AND THE ACADEMIA IN DEVELOPING BIOCOMPOSITES FOR THE AUTOMOTIVE APPLICATIONS**

To harness renewability and sustainability, in the last two decades, there has been an extensive effort aimed at maximizing biocomposite research and applications with both the academia and industry coming together to advance natural fiber- and bio resin-derived composites [29]. Nature conservation and minimization of pollutants from the automotive industry have come on board as serious issues worth immediate consideration; though to manufacturers and buyers, durability, safety, and cost still remain the major yardsticks for the choice of materials. Extensive application of these materials would thus be fully realized only if an optimal balance is struck between the cost, performance, and environmental attributes [30]. The initial step taken toward the commercialization of biocomposites in the automotives was a rather cautious one with most of the innovations much more centered on nonstructural interior components; wood trims, seat fillers, seat backs, headliners, package trays, dashboards, and thermoacoustic insulations for flaws in these parts are not as catastrophic [31–34]. However, with continued research and development in this area, the scoop is fast expanding to more structural parts like seat frames, load floors, pick-up beds, floor pans, drive train, and steering components. Studies have shown that natural fiber-reinforced composites can be applied to where high strength, high stiffness, and low component weight are required [35]. An investigation into the mechanical properties of sisal, abaca, hemp, coir, kenaf, and jute fiber-reinforced polypropylene (PP) composites [36], showed

an increase in the tensile strength and modulus with increasing fiber volume fraction. Their mechanical properties were found to compare well with the corresponding properties of glass mat-reinforced PP composites. In some other cases, natural fiber composites have displayed better specific properties than glass explaining their application potential for end uses that do not require very high load bearing capabilities [37]. Another approach being used both in research and practical application is hybridization; a means of combining bioresources with conventional materials giving products having requisite cost, and performance properties. Suhara et al. [38] found out that a hybrid of 25% weight hemp and 15% weight glass PP-reinforced composite had much better flexural modulus, impact strength, thermal, and absorption properties compared to hemp-reinforced composites and could make a better choice for structural applications where high stiffness and thermal resistances would be required. A life cycle assessment comparison of the impact of hemp fiber-reinforced composites against acrylonitrile butadiene styrene (ABS) composites [39] portrayed hemp’s superiority in accordance with the lifetime environmental impact recommending it to substitute ABS for covering applications in automotives. A similar assessment showed that replacing a side panel for Audi A3 car made from (ABS) copolymer with hemp fiber-reinforced epoxy composite is possible and since hemp’s mechanical properties are relatively good, the probable slight compromise in the performance would greatly be compensated for by the huge positive environmental impact achieved as a result. Despite a myriad of hardships met in incorporating new materials into their production lines, almost all the major automotive industry stakeholders have come up to embrace the campaign for a greener industry.

#### *Original Equipment Manufacturers (OEMs), Tier1 and Tier2 Suppliers*

**Faurecia.** Faurecia, one of the biggest automotive equipment suppliers [40] is headquartered in Nanterre France specializing in manufacturing seats, exhaust, and interiors systems (Fig. 3). It supplies parts such as the dash boards, center consoles, door panels, acoustic modules, and shock absorption systems to Volkswagen group, PSA Peugeot Citroën, Ford, General motors, Renault-Nissan, Toyota, Hyundai, Fiat/Chrysler, and KIA among others. This category of products account for 15–20% of the vehicle weight [41]. The company has been part of the group of auto makers focused on developing technologies aimed at continuously creating a positive vehicle Life Cycle Assessment (LCA) through weight reduction, lowered fuel consumption, and less pollution burden. A program code named “BioAttitude” has had Faurecia introducing a string of new technologies that is natural fibers for lean injected design (NAFILEan) and LignoLite to the market. NAFILEan is processed by traditional injection molding machines enabling the formation of

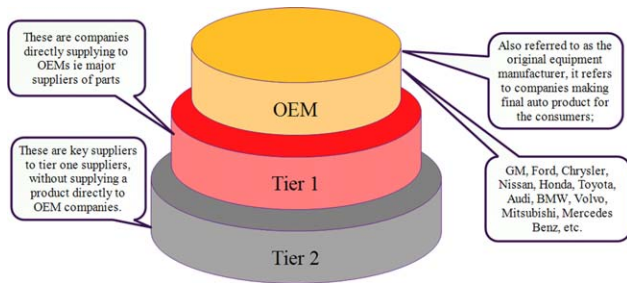


FIG. 3. A schematic diagram of the automotive supply chain. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

unique complex shaped interior products in form of center consoles, instrument panels, and door panels such as was the case for Peugeot308 [42]. During the forming process, utilization of hemp in the mixture enables a 20% weight saving and a 20–25% reduction on the overall environmental impact during component's life cycle [43]. Likewise, LignoLite is a product of traditional compression procession molding combining to up to 85% wood fibers with oil-based binders. This has been used in creating components for Mercedes Benz S-class door panels realizing a saving of up to 45% on the door panel carrier weight. Another weight reducing innovation undertaken by Faurecia has involved the use of *Flaxpreg*; a green and light, very long flax fiber-reinforced composite sandwich. With the use of unidirectional long nonwoven flax fibers as reinforcement able to facilitate drastic weight reduction coupled with load bearing capabilities for application in load floor of the vehicle passenger compartment [44].

**Goodyear and Dupont.** Goodyear, a global automobile tire manufacturing company makes tire for among others; saloon cars, light trucks, commercial trucks, SUVs, and race cars. Ford auto supplier has been working together with DuPont chemical company to codevelop renewable alternatives for petroleum-based chemicals and fuels. In 2009, together with Genencor, they introduced a biomass-derived Bio-Isoprene to the market [45] and Ford has since been using these modified corn starch infused tires on its European market Fiestas considerably reducing the tire weight of a brand well known for its high fuel consumption [46]. BMW is also considering using them on their version 3 of saloon cars. Another energy saving bio tire GT-3 BioTred, produced through a partnership with an Italian biomaterials firm Novamont is attracting interest from a number of automakers. Goodyear has had some of the carbon black and silica in the tire formulation replaced with biomaterials producing a 5% reduction in fuel consumption, 50% reduced rolling noise with a 10% improvement in the wet breaking performance [47]. An innovation for which they earned "Environmental Achievement of the Year Award" at the 2010 Geneva Motor Show [48]. Whereas natural rubber derived poly-

isoprene still offers the best quality, it is not enough to satisfy the available demand in addition, since the production is only concentration in particular regions, political instabilities in such areas or plant disease outbreaks would hugely affect the automotive industry. Exploration of biomass-derived isoprene an integral part of the automotive tire components is taking shape. Faurecia has shown that, switch grass, sugarcane molasses, and woody biomass can offer the alternative source for BioIsoprene® (2-methyl-1,3-butadiene) by converting the cellulose involved to sugars which are in turn converted into isoprene. Both MVA and DXP pathways have been used to produce the precursors for the synthetic BioIsoprene® using fermentable sugars as feed stock [49].

**Johnson Controls Interiors.** Johnson Controls Interiors, an American company too specializing in automotive seatings and interiors, has been investing in innovations aimed at cleaner consumption in their product end users doing this through research on the application of natural fibers and polyols in the interior auto components including door panels and seats [24]. Recently, they embarked on a large-scale production of biomaterial parts, using a wet press processing-based method to produce wood fiber components for vehicle interiors. In the latest process, a carbon fiber mats premoistened with resin are pressed in between the forming tools resulting in the expulsion of the excess resin through mold edges to give high fiber density body parts [50].

**Rieter Automotive.** This is a global supplier of parts including the engine bay (engine covers, hood liners, outer dashes, and water box shields), interior trim (headliners and parcel shelves), trunk (trunk side trim and trunk flooring), and underbody (underbody shields, floor pans, heat shields, wheelhouse and outer liners). In 2004, the company began a commercial production of spare wheel pan covers for the Mercedes A-Class (W169) car in which most of the glass fibers had been replaced with abaca (banana) natural fiber reinforcements. This project which took 18 months to accomplish before roll out was found to lower the cost and weight with a less significant effect on the product quality. The life cycle analysis of the product showed a reduced primary energy use of around 10% for abaca fibers [51]. Rieter also made a load floor of Maserati Quattroporte from wood fiber reinforced PP which is now a structural layer for trim parts in the passenger compartment and in the trunk area. Under the "bioacoustics" project, Rieter has been developing the state of art light weight ecofriendly sound packages to improve the recycling of individual components, reducing environmental impact and overseeing a significant reduction of energy consumption for manufacturing of components [52]. The company won the JEC Composites Award 2005 for the design of the natural fiber-reinforced thermoplastic composites for an under-floor module with integrated aerodynamic, thermal, and acoustic functions [53].



FIG. 4. An illustration of natural fiber use in the Ford flex quarter trim panel, storage bin and cover line assembly (20% wheat straw-reinforced PP). Reproduced from the Ref. [56], with permission from Woodhead Publishing.

**Other Suppliers.** A number of other auto parts suppliers have come up to positively grace a green industry and “sustainable mobility.” Visteon Corporation (VC), an American global automotive parts company that primarily supplied the Ford motor company entered into a joint venture with the Kafus biocomposites in 1999 to create ecofriendly car interiors. A one step molding process was used to produce 3-D automotive trim components from a blend of bast fibers (kenaf and hemp) and PP resin [54].

## AUTOMOTIVE MAKERS

### Ford

The Ford Automotive Company in North America has gone on to embrace its early twentieth century legacy of mustering a close partnership with agriculture. Their R&D centers in the United States, Aachen Germany, and Brazil have been developing automotive foams and composites from renewable resources as a recipe for weight and carbon footprint reduction. This has been done in a collective effort involving a number of stakeholders amongst them farmers, researchers, resin producers, tiers, equipment manufacturers, chemical companies and universities. The life cycle analyses comparing soy foams with traditional petroleum-based foams show a net decrease of 5.5 pounds of carbon dioxide per pound of soy oil used [3]. Thus embracing bio composites can be a big step toward decreased dependency on petroleum and increased utilization of renewable agricultural resource. Ford currently has soy foam seats in more than 8 million vehicles on the road and this is believed to be reducing petroleum oil usage by more than 5 million pounds annually compared to when conventional materials are in use.

In 2008, Ford Motor Company partnered with Lear Corporation to develop soy-based seat foam for the Ford Mustang, and bio-based cushions were introduced into more than one million Ford Lincoln and Mercury vehicles in 2010. Similar developments were done with a number of other Ford brands including; Expedition, F-150, Focus, Escape, Mercury Mariner, Lincoln navigator, and Lincoln MKS [55]. Tests on wheat straws have also revealed good mechanical properties and ability to stand a test of time prompting their use in 2010 Ford flex crossover injection molded storage bins. Hemp-propylene composites formed into front grill of Ford Montageträger [48] while 100% castor bean oil derived nylon-11 was used in the fuel tank tubes offering close to 1 million pounds carbon dioxide emission reduction in a year (Fig. 4).

### Mercedes Benz and Daimler Chrysler

In the modern era of automotive biocomposites, the initial Mercedes Benz innovation involved using jute-reinforced plastics for the interior door panels of their 1994 E-Class model [57, 58]. The door was made with flax/sisal fiber mat-reinforced epoxy matrix giving a weight reduction of about 20%. In 2000, Mercedes began the use of polyester/flax-reinforced composites in the engine encapsulations in a number of their bus brands; EvoBus, Travego, and Setra Top-class. A 5% weight reduction was got with the use of natural fiber-reinforced UP-resin in the setra series engine [59]. A total of 27 interior natural fiber-based parts were used in the assembly of 2006 Mercedes Benz S-class; wood fibers in the inner section of the front door linings, the driver’s seat back rest and injection molded retaining hook, flax fibers



FIG. 5. Mercedes Benz E-class components containing flax, hemp, sisal, and wool. Reproduced from the Ref. [48], with permission from Springer. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

in parcel shelves and rear trunk covers, wood veneer in trim strips and panels. This 73% increase in the use of renewable materials as compared to the previous model contributed a total of almost 43 kg to the total car weight [60, 61]. Mercedes-Benz C-Class models built in South Africa had their rear panel shelves made from sisal-reinforced composites. According to Professor Heinrich Flegel, director of production technology at the Daimler-Chrysler Research Center in Ulm Germany, the use of natural fibers reduced the weight by 10% and lowered the energy needed for production of these units by 80% with



FIG. 6. Mercedes Benz S-class door panel. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

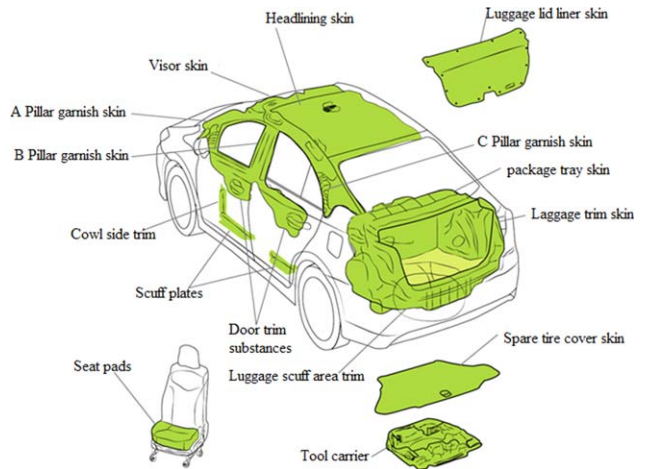


FIG. 7. Bio-based material derived parts in the Lexus CT200h. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

the cost of the component 5% lower than the comparable fiberglass-reinforced components [18]. The production of this brand including processing fibers, and manufacturing of components was transferred to Daimler Chrysler in South Africa helping to involve the sisal farmers and financially empowering them [62]. In 2002, Daimler-Chrysler researchers patented a new blend of PP-reinforced abaca fibers supplied from Philippine Manila Cordage Company, to replace glass in 2004 A-Class coupe spare tire wheel covers earning Mercedes-Benz, the 2005 society of plastics engineers (SPE) innovative award in the “environment category” [59, 63]. In recognition of their successful fabrication of an air filter system from bio polyamide, Daimler, BASF, and the University of Braunschweig received the 2009 VDI award for the innovative application of plastics. The polyamide 6.10 was produced from hexamethylenediamine, 60% by weight of castor oil-derived sebacinic acid reinforced with 10% glass fibers and 20% mineral substances managing a 6% weight saving, better dimensional stability, lower water absorption and improved flow characteristics compared to the conventional fossil-based polyamide (Figs. 5 and 6).

### Toyota

Toyota’s first commercial effort to go green involved use of PLA matrix from sweet potatoes and sugar cane reinforced with Kenaf fibers in its RAUM 2003 model spare tire cover [64]. It then used Kenaf fiber-reinforced PP composites to make Mazda door trims and other interior parts in Indonesia. Soy-based seat foams were used in 2008 Rav-4 models while bio-based PP/PLA found application in the side trims, door scuff plates, tool box area, floor finishing plate, and package trays of the Lexus CT200h [65]. In 2009, Toyota worked on what was perhaps one of the most challenging innovations in bio-based composite era, involving the use of Zytel RS bio-based nylon for the 2010 Toyota Camry Sedan radiator end



FIG. 8. front-end grill front-end grill opening reinforcement for the Ford Montageträger. Reproduced from the Ref. [48], with permission from Springer.

tank. Jointly developed by systems supplier, toolmaker, and molder DENSO Corp. (Kariya, Aichi, Japan) and resin supplier DuPont Automotive (Troy, MI), the parts were injection molded from a 30% short glass-reinforced blend of polyamide (PA 6,10 or nylon 6,10) resin formulated with 40% bio-based monomers obtained from castor beans. This demystified the inability of biocomposites in demanding applications requiring high impact strength, chemical resistance, creep resistance, and long term heat age performance from exposure to a broad range of temperatures and pressures. In 2011, the company pioneered the use of a bio-based polyethylene terephthalate (PET) resin in the auto industry. This new material reportedly, had better heat resistance, more durability, and less susceptibility to shrinkage compared to the corn-based parts used in the Lexus-CT200 luggage compartment lining [59, 66] (Fig. 7).

#### Volkswagen

This is the biggest Germany automaker, third largest in the world headquartered in Wolfsburg Germany [67], with a number of vehicle brands as its subsidiaries including Audi, Bentley Motors, Bugatti Automobiles, and Lamborghini. They are the leading auto maker in terms of investment in research and development. Natural fiber-reinforced composites were used for door inserts, seat backs, rear flap lining and parcel trays in its Golf A4 and Golf A4 variant 1998 models [62]. In 2000, Audi launched the A2 midrange car in which door trim panels were made of polyurethane reinforced with flax/sisal hybrid mats [3, 37, 68].

#### General Motors

Commonly known as GM, General Motors is headquartered in MI and through its subsidiaries, manufactures, markets, and distributes vehicles and vehicle parts.

With production units in 37 countries under 11 brands; Chevrolet, Buick, GMC, Cadillac, Baojun, Holden, Isuzu, Jie Fang, Opel, Vauxhall, and Wuling. Wood fibers are being used in seatbacks of Cadillac DeVille and in the cargo area floor of GMC *Envoy* and Chevrolet Trailblazer [69]. The inner door panels of 1995 Opel Corsa were made using flax fiber-reinforced PP composites. Cambridge Industry in MI is making flax fiber-reinforced PP for freightliner century COE C-2 heavy trucks as well as rear shelf trim panels for model 2000 Chevrolet impala [70] (Fig. 8).

#### Bavarian Motor Works—BMW AG

This German Automobile, motorcycle and engine maker, has been using natural fibers since the early 1990s including in their BMW3, 5, and 7 series [71] with each of the BMW7 series having 24 kg of renewable materials in the interior door linings and paneling; wood fibers are used to enclose the rear sides of the seat back rest and cotton fibers used as sound proofing [72]. Dräxlmaier Group made a compression molded panel door for the BMW7 series sedan using a unique thermosetting acrylic copolymer, consisting of modified polyacrylic acid, polyalcohol crosslinker trademarked Acrodur® from BASF and prepreg natural fiber mats from Dittrich and Söhne GmbH [71]. Acrodur® has a high wet out for natural fibers and this allows production of composites with loadings as high as 70%. It does not discharge any harmful substances to the atmosphere such as phenol or formaldehyde during the crosslinking process making it safe to work with. Using Acrodur/sisal composite instead of the original acrylonitrile butadiene styrene (ABS) allowed engineers to decrease the wall thickness from 0.25 in./6.35 mm to 0.094 in./2.4 mm, producing a 6-lb/2.7-kg weight saving on the four-door sedan yielding a lowered fuel consumption, reduced emissions and better vehicle recyclability [73]. Lately, BM is keen on advancing



FIG. 9. The lower door panel for the BMW7 series sedan made with compression molded natural fiber mats and BASF acrylic copolymer. Reproduced from the Ref. [71], with permission. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

biocomposites into structural automotive parts and trials are already on with fender liners, shields, bumpers, and components of the suspension systems [26] (Fig. 9).

### *Other Brands*

Mitsubishi motors together with Fiat SpA have developed interior vehicle components by combining bamboo fibers and a plant-based resin polybutylene succinate. PLA, nylon/flax have been used in making of floor mats, hemp/cotton for indoor cladding, seat back linings, and floor panels. Fiat is using castor oil-derived polyamides and soy-based polyurethanes to replace petroleum resins in a number of its models. It is also increasingly using biofillers in reinforcing some of the plastics and elastomers used in production. In 2011, the use of castor oil-based long chain polyamide in some fuel lines won Fiat and DuPont the Society of Plastics Engineers' (SPE) Automotive Innovation award in the environmental category [74]. Volvo has been using renewable materials such as hemp, jute, rapeseed, and soy resins in its products. It is also working on making cars with parts such as dash boards and ceilings out of natural fibers. French auto maker Citroen has reportedly used 11% green materials in its latest C3 Picasso (excluding tires). Parcel shelves, boot linings, door panels and mud guards have been made with recycled from wood, vegetable fibers, and other renewable resources.

## **MANUFACTURING PROCESSES USED IN MAKING BIOCOMPOSITES**

Several composite making processes are in application today, however, not all of them can be applied in the forming of biocomposites for the automotive applications. Due to the special properties of the materials involved, for a forming process to be used, it should ensure minimum thermal degradation. Thermoset and thermoplastic press molding take a very big chunk of forming methods used [75]. Compression molding is in particular an established and proven technique for the production of extensive, light weight, and high class interior parts in medium and luxury cars for it is cost effectiveness, being suited for light construction, good crash resistance, and deformation properties. In this process, flat semifinished products or hybrid fleeces that are either larger or same size as the form are cut exactly to the size of the desired part which together with the matrix are put into the preheating station (mold) heated to the melting temperature of the matrix material that is subsequently guided into the pressure tool unit, condensed, and reshaped [76]. Different auto makers have modified this process to optimize the positives. Mercedes Benz E-class door were made by reinforcing epoxy with sisal fibers, placing needle punched nonwoven fiber mats into a heated mold followed by pouring a heated liquid resin and then pressing until curing had been attained [77]. Ford motor company

has undertaken a number of projects to find out the feasibility of sheet molding compounding (SMC) as a potential procedure for forming natural fiber-reinforced auto parts. This composite making process involves dispersing long strands of chopped fibers on to a bath of resin. With the resulting material used as "ready to mold" primarily in compression molding. Though glass fibers are the predominantly used reinforcement for this application, an investigation has shown that hemp fibers, nonwoven hemp mats, hemp twines, and their hybrids-reinforced PET and vinyl ester SMC could offer mechanical properties comparing well with traditional glass-reinforced SMC [78]. In a similar way, Libby Berger and Dan Houston [79] made SMC using soy-based resins reinforced with glass and carbon fibers, respectively, comparing the products with parts made from similar reinforcements using petroleum-based resins had glass-reinforced soy-based materials displaying properties matching well with those of petroleum-based materials. Faurecia is making use of "Microject" technology; a technique involving injecting a combination of resin and an inflating agent or gas to reduce the density of injected parts without affecting performance. This gives a 20% weight reduction when used in door panels, or center console parts compared with the traditional injection system. This technology has so far been implemented in the instrument panel and the center console of Ford Escape. In another size reduction and materials optimization process, Faurecia has introduced natural fiber PP (NFPP) in the smart (Daimler) city car instrument panel top cover and knee pad; it uses 50% PP and 50% flax fibers. This technology supplies the additional benefit of reduced cycle times by allowing for a one-step compression and covering process; a technique applied to create the Volkswagen Golf door panel. In 1999, a Bayer's Hennecke Machinery unit developed automotive polyurethane composites marketed as Baypreg<sup>®</sup>. Making these composites involved a system using different combinations of reinforcing mats and honeycomb cores to manufacture interior vehicles parts from natural fibers. Initially, Baypreg system used flax and sisal fiber mats supplied in widths suitable for the parts being made and weight ranging from 700 to 1,200 g/m<sup>2</sup>. These would be dried to the moisture content below 3% and then cut to the suitable size. The cut mat would then be sprayed on both sides with the polyurethane mixture, using a high-pressure metering device and self-cleaning mix heads and then heated in mold for shaping [80]. Its first commercial application was in the inner door panel for the 1999 Germany made S-Class Mercedes-Benz, in which 35% Baypreg semirigid Polyurethane (PUR) elastomer from Bayer was mixed with 65% flax/hemp/sisal blend to make a 2-mm-thick door panel [81]. The technology provided an exceptionally high stiffness to weight ratio by combining light weight properties of honeycomb core with the high strength properties of the fiber-reinforced polyurethane skin and has been found cost effective with a better industrial hygiene compared to

glass fibers. It has so far been used for door panels, spare tire covers, load floors, sun shades, and other interior trim pieces by a number of automakers including Audi, BMW, and Mercedes [48, 82]. In 2010, Baypreg was used to produce a bonded two-piece monocoque structure—similar to those used in Formula-1 cars; for the safety cell, subframes, body panels, and interior surfaces of Mazda's MX-0 concept vehicle and the trial demonstrated a high percentage reduction in the automotive weight [83]. For automotive parts, whose application require unique and complex shapes, injection molding has been used. This involves injection of materials into a mold done with a low molecular weight polymer to maintain low viscosity [84]. DaimlerChrysler developed an extrusion press processing for production of flax-fiber-reinforced PP composites for its interior auto parts in a technique known as express processing [85]. This involved depositing of natural fiber nonwovens in a tempered mold where thermoplastic melt-films were then laid on by a mobile extruder. The structural order consisted of three layers; two layers of nonwovens on the bottom and the other one top, with a melt-film sandwich in between [86]. In 2013, Faurecia SA launched the production of injection molded bio composites combining hemp and PP in the door panels of Peugeot 308 which saved up to 400 g per door panel [87].

## **PROMISING BIOMATERIALS FOR THE AUTO INDUSTRY BIOCOSMOS RESEARCH AND APPLICATIONS**

The biomaterials so far in progress and those under study for application in the automotive composites are either used as resin or reinforcement. Conventional resins that have for long dominated the industry have petroleum as the source for feedstock and energy during manufacture. Likewise, glass and carbon fibers have been dominating as the reinforcements. As noted elsewhere in this paper, there is increasing need to find renewable alternatives to counter the environmental concerns of an oil-based economy to reduce their carbon footprint [88]. A number of alternatives are being considered with some of these already showing promising performance while others are at the stage of development. PLA is a thermoplastic aliphatic polyester derived mainly from sugar obtained from maize, sugarcane, sweet potatoes, biomass resources such as disposed paper, leftover food, residual lumber, straws, and chaff [9]. PLA reinforced with natural fibers is already being used in the composites for the automotive interiors where studies have revealed a considerable suppression of the carbon dioxide with up to 85% reduction compared to PP plus an improved thermal and impact performance [89]. Soy oil, another promising material for the automotive biocomposite [90] was the earliest farm material pondered for application in the industry. A research initially undertaken by Ford automotive under the close watch of Henry Ford in 1932 was bankrolled to the tune of 1.25 million dollars, involved ear-

marking a 7,400 acres soybeans farms in Southeastern MI. In 2005, Cargill introduced a brand of soy-based polyols, which it called BiOH and accordingly reported that “for every million pounds of petroleum-based polyols replaced with BiOH polyols, nearly 2,200 barrels of crude oil could be saved, if the project was to be adopted commercially [91]. Mitsubishi Chemicals and Faurecia partnered to develop an optimized polybutylene succinate (PBS) in what was branded a BioMat project. The product has a potential to replace PP, PET, and polyethylene (PE) resins in automotive composites because of its high tensile strength and heat resistance, effort is thus underway to develop PBS/hemp fiber combination for commercial roll out. In 2013, automotive interior systems Tier I Toyota Bashoku Coporation and Toyota Motors' innovation arm (Toyota central R&D labs) developed a technique for making a bio-based plastic alloy with top-class impact strength. The alloy, a combination of 100% bio-based resin polyamide-11(PA-11) derived from castor bean plants and PP reportedly had an impact strength surpassing that of polycarbonate alloys; a feat achieved by controlling the phase structure of PP and PA-11 at a nanolevel [92]. BASF, one of the industry's leading suppliers of resins, and coatings has developed an environmentally compliant and highly performing resin Acrodur<sup>®</sup> that works efficiently well with natural and synthetic fibers. This is a water-based and formaldehyde-free crosslinking acrylate boasting of excellent binding properties. The underlying technology is based on the thermal crosslinking of polycarboxylic acids with a multifunctional alcohol. Acrodur<sup>®</sup> can serve as an alternative to epoxy and polyurethane-based binders in producing light weight composites using conventional processing equipment and has been used on the natural fibers such as flax, hemp, sisal, and wood to make shaped panels for automobile interiors [93, 94]. Toyota is using bio-based polyesters and PET in some of its light-weighting endeavors. Bio-based poly trimethylene terephthalate (PTT) developed by DuPont under SORONA trademark name is another promising bio resin. WangJun Liu et al [95], characterized injection molded glass fiber-reinforced polytrimethylene terephthalate composites and found them to have convincing mechanical properties to enable them application in the automotive industry. Other potential bio resins include; thermoplastic copolyester elastomers (TPC-ET) or bio-based polyamides, polyhydroxyalkanoates (PHA). General Motors is using PP from wood for seatbacks in the Cadillac DeVille and flax for trim and shelving in the Chevrolet Impala. Ford is using wheat straw-derived PP for the interior storage bins in the Ford Flex and coconut derived PP for the load floor in the Focus BEV. The Lexus CT200h contains PE made from bamboo and corn in its luggage compartment, speakers, and floor mats. Also, a number of Mercedes-Benz models have PE from flax in the engine, transmission cover and the underbody panels an example being compression molded flax—PP composites for the A-Class DaimlerChrysler cars [48]. FXI has developed a high grade low density foam trademarked GreenBlend<sup>®</sup> [96]



FIG. 10. Bcomp's ampliTex light biaxial 0/90° flax fabric capable of high performance applications. Reproduced from the Ref. [99], with permission from Elsevier. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

using natural oil polyol meant specially for the production of foam-fabric/vinyl laminates for the automotive seating and the interior trim applications including headrest, armrest, visors, and door panels. A number of reinforcements including kenaf, hemp, flax, abaca, jute, and sisal are being studied for the applications [97]. Flax is still the most favored enjoying a lion's share of the European industry [98]. Natural fiber company Bcomp limited has made ampliTex®; low twist, low fabric areal weight flax yarns with the low twist offering good alignment of fibers capable of increasing the composite strength by up to 20% when used to replace high twist yarns, capable of a 50% weight reduction when used to replace glass [99] (Figs. 10–12).

### BENEFITS OF THE BIOCOMPOSITE USE TO THE AUTOMOTIVE INDUSTRY

Though glass fibers remain the major source of reinforcements for the automotive-based composites, biocomposites are a promising remedy for greenhouse gas emissions and depletable petrochemical-derived products [103]. The energy requirements for processing glass fibers are exorbitant compared to natural fibers; whereas it takes 6,500 British Thermal Units (BTU) of energy to produce one pound of Kenaf fibers, one pound of glass fibers will require 23,500 BTUs [18], besides, natural fiber products can be incinerated or safely composted after their purposeful lives. This method of degradation theoretically results in no net addition to carbon dioxide emissions into the atmosphere as plants from which natural fibers have been obtained normally sequester atmospheric carbon dioxide during their growth. In that case, the amount of CO<sub>2</sub> released during the burning process is negligible as compared to that taken up by the plant throughout its lifetime which gives a very favorable carbon balance [104]. According to Malgorzata et al. [66], cultivation of hemp *Cannabis sativa* on 1 ha of land results in the absorption of

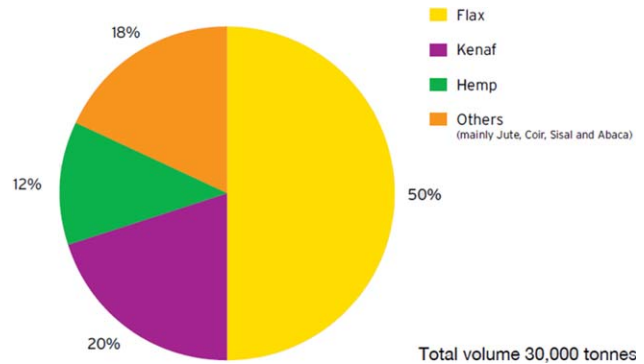


FIG. 11. Use of natural fibers for composites in the European automotive industry 2012. Reproduced from the Ref. [98], with permission from Nova institute for Ecology and Innovation. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

approximately 2.5 metric tons of carbon dioxide from atmosphere during one growing period, with about the same amount of jute absorbing as much as 2.4 metric tons of carbon, conversely, producing 1 ton of PP resin emits more than three tons of carbon dioxide into the atmosphere. Production and disposal of other conventional fibers such as glass, carbon, and aramid fibers results in the release of equally vast quantities of carbon dioxide to the atmosphere along with NO<sub>x</sub>, SO<sub>x</sub> gases, and dust that are potential hazards to the environment and its inhabitants [52, 58, 105]. Josh et al. [106] did a life cycle analysis (LCA) comparing the fiber weight and energies needed to produce different composites, as well as their resulting impact, natural fiber-reinforced composites showed environmental superiority to glass composites in accordance with the resultant effect on the efficiency of the automotives and end of life incineration. Natural fibers have also exhibited better mechanical performance in some particular applications like the case of Mercedes Benz door trims, where the lateral impact fracture properties were excellent [107]. With the automotives experiencing lots of shock and vibrations during motion, appropriate materials have to be used to enable suppression and damping. Besides, there is always discomfort generated from engines, exhaust systems, gears, and wheels in form noise, heat, and electrostatic charges, so natural fibers offer a remedy by neutralizing all these [108]. They absorb humidity increasing interior comfort values and the fact that most plant fibers have a hollow cellular structure with a maximum density of 1.5 g/cm<sup>3</sup>, endows them with high specific strength, stiffness and weight reduction aiding a low fuel consumption regime and subsequently reductions in air pollution; energy efficiency is influenced by the weight of a moving object [66]; a property that has as well been handy in maximizing thermal and acoustic comfort [93] which are of paramount importance to the general wellbeing of the passengers. Coconut fibers bound with latex used for seat cushions exhibited better moisture absorption capabilities offering better interior humidity and comfort as compared to conventional fibers. Flax/sisal

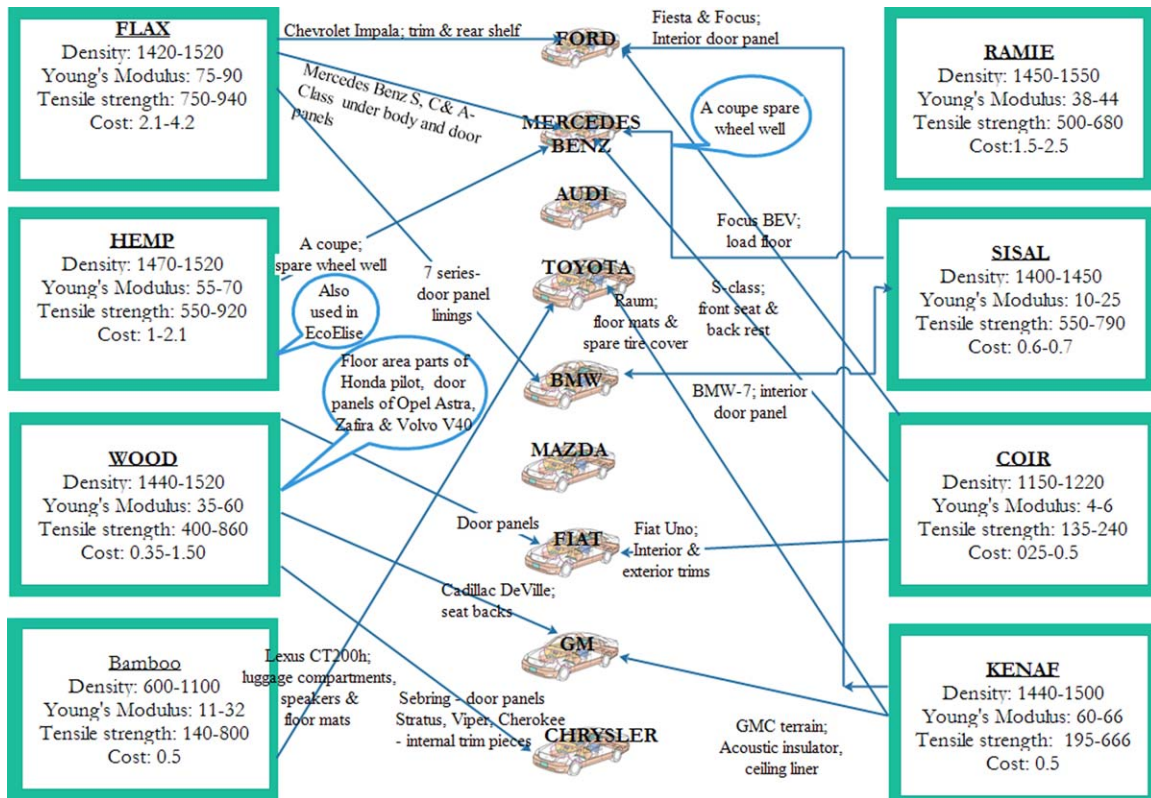


FIG. 12. Fiber properties and their recent application scope in the automotive industry. Natural fiber properties sourced from [100–102], cost (USD/kg), density ( $\text{kg/m}^3$ ), tensile strength (MPa), and Young's modulus (GPa). [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

reinforcements allow molding of intricate shapes and thermoset polymers are used as binders for cotton or similar fibers in the production of inner trim parts and insulating or damping materials [119]. Hemp has a higher strength to weight ratio than steel, is considerably cheaper to produce

delivering same performance for lower weight while it is able to achieve strength of up to 25–30% for the same weight [85, 110]. Natural fibers are nonabrasive enabling them high fiber loading applications without extensive damage to the compounding and molding equipment as is

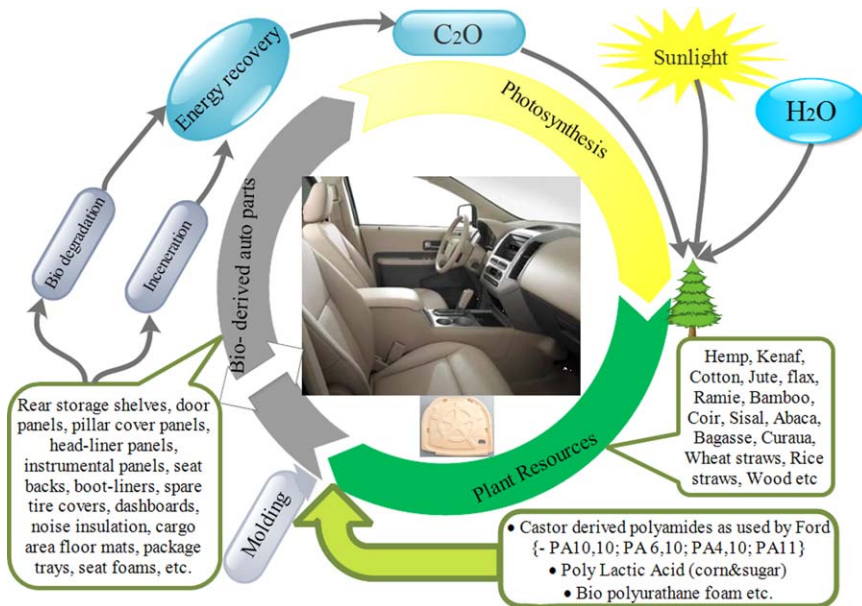


FIG. 13. Schematic diagram of carbon neutrality in bio-derived automotive parts showing the sequestering of carbon dioxide from the degraded parts by the plants. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

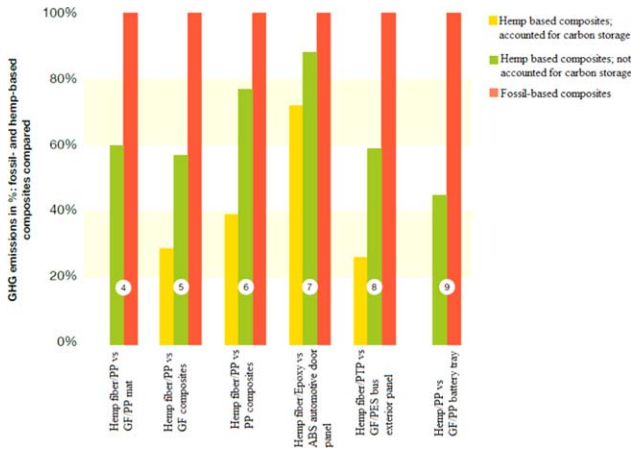


FIG. 14. Comparison of greenhouse gas emission potential of hemp-based composites versus fossil-based composites. Reproduced from the Ref. [98], with permission from Nova institute for Ecology and Innovation. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

always the case with glass fibers. Tests have proved them a safer option especially in times of collisions and crashes; in the tenth annual conference for the Society of Plastic Engineers(SPE) [111], demos of the deformation modes for the automotive interiors from natural and glass fibers, showed glass composites ripping to form sharp edges upon deformation (Figs. 13–15).

### Challenges

Despite the theoretical potential of natural fibers and the promise of replacing glass as a big force in automotive composites [113], there are many inherent drawbacks

in their structure and properties limiting their application potential to comply with the challenging and often too demanding requirements that an automotive is subjected to such as high thermomechanical performance at both short term (e.g., impact) and long term (e.g., creep and fatigue) exposure to corrosive chemicals and fluids [114]. It is thus with caution that the industry is investing in an uncertain venture against a well-established structure. For developing a whole new infrastructure needs patience and considerable capital input which affects the bottom line price and profit on the final product. Despite some agricultural products such as soybeans and corn offering the promise of possible industrial roll out, they are a major integral of the food chain. Also, the processability of bio-material reinforcements is not without trouble for the tendency to form aggregates during processing, low thermal stability, low moisture resistance, and large variation in their properties make it hard for them to make viable composites [115] which in turn makes it a tough task to design structures with uniform structural and functional stability during storage and use, yet susceptible to fast microbial and environmental degradation upon disposal [116]. Despite some natural fibers having properties comparing well with glass fibers, their properties show serious variations affecting consistency of the resulting composites; for example, despite flax fibers having better stiffness, it is spread over a range of 50–100 GPa compared to E-glass –72 GPa [117], thus, the latter is still preferred for application where reliability and uniformity are a priority. The presence of pendant hydroxyl and other polar groups within various constituents of the fibers makes them hydrophilic leading polymer-reinforcement adhesion problems. Also, since there is a distinct gap between the natural fiber processing temperature and that of

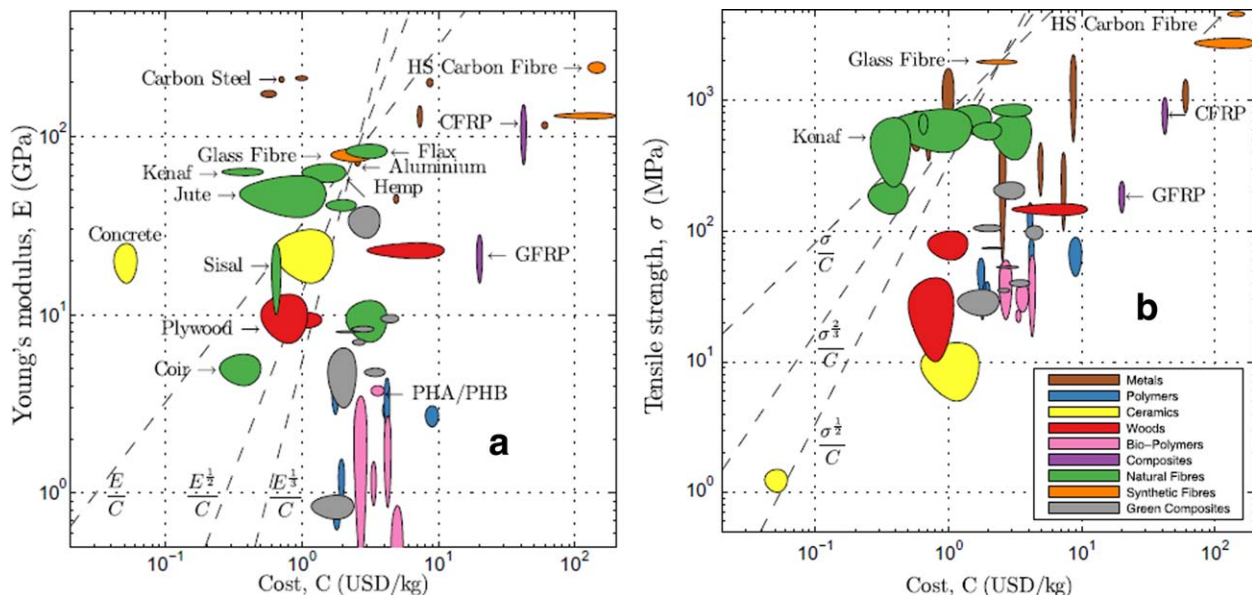


FIG. 15. The comparison of the relative mechanical environment and the economic properties of green composites compared to other materials; (a) Young's modulus versus cost, (b) Tensile strength versus cost. Reproduced from the Ref. [112], with permission from Elsevier. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]



FIG. 16. Eco Elise green technology using sustainable materials and cleaner manufacturing processes for weight and carbon miles reduction; (a) Lotus Eco Elise car, (b) the lotus eco Elise seats. Reproduced from the Ref. [139], with permission from Elsevier. [Color figure can be viewed in the online issue, which is available at [wileyonlinelibrary.com](http://wileyonlinelibrary.com).]

conventional fibers, this prompts a need to overhaul the available processing technology which together with some other prepaid costs—transporting and material would make the end product less cost effective [54].

#### THE FUTURE OF BIOCOMPOSITES; THE MAINSTREAM RESEARCH PROGRESS AND GOVERNMENTS' INVOLVEMENT IN ADDRESSING THE DRAWBACKS SO FAR EXPERIENCED

The automotive industry's interest in these materials has been gradually progressing over the last several years but despite a significant research so far done, they are yet to achieve full commercial potential, and thus, their demand in the industry is expected to continue rising. European auto makers are still regarded the leading at implementing natural-based materials in the industry having purchased an estimated 20,000 tons of fibers as of 2010; a figure expected to rise up to 50,000 tons by 2015 [118]. Natural fibers are a promising practical means of achieving weight reduction in automobiles and with nearly 75% of gas energy consumption directly related to factors associated with the vehicle weight [119], auto companies have to keep up a consistent research and technical innovations in this area. New and more efficient materials are being developed especially through hybridization to address the shortcomings experienced with the earlier research and application. Dr. Amar Mohanty at the University of Guelph and Dr. Mohini Sain at the University of Toronto are working on a research to develop a high impact thermoplastic natural fiber-reinforced composites from polylactide (PLA), poly (3-hydroxybutyrate-hydroxyvalerate-PHBV), and PP blends [120], whereas Robertson et al. [121] modified PLLA and soy oil properties by blending with PLLA/polySOY attaining a tensile toughness to the tune of four times greater than that of unmodified PLLA, with corresponding strain at break values as high as six times unmodified PLLA. For the injection molded auto parts, PLA has shown low impact resistance, susceptibility to hydrolysis, poor compression,

plus a long solidification time during the injection molding process. Takayama et al. [122] of the Toyota made a PP/PLA by incorporating PLA within hydrolysis resistant and highly formable PP with the help of an appropriate compatibilizer able to disperse PLA within PP with precision. In a similar way, researchers at Toyota have determined that the use of an appropriate nucleating agent on low molecular weight, high optical purity PLA facilitates the process of crystal growth during crystallization which is turn critical for heat resistance and formability of the of the resin [123]. Dahlke et al. [124], developed and successfully test ran a fiber-reinforced rigid foam system based on plant polyols (made by ring opening addition from epoxidized soya or sun flower oil and ethylene glycol). The product-*ElastoflexE3517* with 60:40 fiber-polyurethane distribution with a total of up to 80% renewable materials showed excellent compatibility with aromatic isocyanates and comparable mechanical properties to glass for interior car trim applications [124, 125]. Research has projected that composite materials developed from a combination of perennial grasses, soy/oat hulls, nanocellulose, and lignin-based carbon fiber reinforcements in ethylene-propylene diene-terpolymer (EPDM) blended with carbon black and talc could be developed into various automotive parts with impressive mechanical properties suited for structural applications [126]. Researchers at Faurecia are focusing on eliminating up to 59 kg from an automotive by 2020 by making use of natural fibers and hybrid composite parts [71]. While underway is the *BioMat* project (Faurecia), aimed at engineering injection molded materials with 100% natural fibers in a biomatrix. In 2010, the Royal DSM, a global life and Materials Sciences Company patented Palapreg<sup>®</sup> ECO P-55-01, a high performance 55% biorenewable thermoset resin compatible with a range of reinforcements including glass, carbon, and natural fibers and suitable for sheet and bulk molded vehicle parts [127]. DSM also developed EcoPaXX<sup>®</sup>; a high performance 70% renewable polyamide (PA410) derived from castor oil beans

boasting of excellent chemical resistance, low moisture absorption, a high melting point, and carbon neutrality [128]. The ECOPAD research team made up of experts from the University of Exeter's Advanced Technologies department (X-At) and a consortium of industrial partners representing brake pad manufacturers, suppliers, and end-users developed a technology using hemp fibers as enhancements in brake pads [129]. The product, offered the same frictional performance as aramid fibers. *ECOplast* [130], a 4-year research project that ran up to 2014, incorporating 13 partners coming from five European countries led by the Spanish Galician Automotive Technological Centre (CTAG) aimed at developing tailor-made biocomposites for the automobiles. Toyota Motor Corporation has been focusing on replacing 20% of the plastics used in their automobiles with bioplastics by 2015. In their 2012 annual report, Grupo Antolin; a Spanish multinational company designing and manufacturing interior automotive components acknowledged the increasing awareness of their customers (auto manufacturers) and vehicle users of the impact of the auto sector on the environment. Also, several governments and environmental bodies have come on board to boost this renewable materials research through extension of tax credits, extending technical, and monetary support toward implementation of various environmental policies, and encouraging a more environmentally friendly disposal of end products from the auto industry [131]. In North America, where there is the biggest concentration of automotive industries, governments are getting involved through extension of research funds to the institutions and industries. In 2008, Canadian government introduced the Automotive Innovation Fund (AIF) allocating 250 million Canadian dollars over a period of 5 years to automotive firms involved in research and development of greener and more fuel efficient vehicles. Up to \$54.8 million was committed to Linamar Corporation's Green and Fuel Efficient Power train Projects, with a projected cost up to \$365 million by 2013 [132], likewise, Ontario bio-assisted several automotive suppliers through extension of grants toward commercialization of bio-based automotive parts.

### **PROJECTION OF THE BIOCOSPOSITE PROSPECTS IN AUTOMOTIVE INDUSTRY THROUGH CONCEPT CARS**

Over time, automakers have projected the future significance of biocomposites in the automotive industry through bioconcept cars. Though these seldom make it to the market, they help give the industry an idea on the possibilities of particular materials and designs. In 2001, Toyota Motor Corporation developed an ES3 concept car exhibiting the affordability of the environmentally friendly technologies using sustainable materials and cleaner manufacturing processes [64]. This had hemp/polyester composite body panels, sisal carpets, light

weight seats upholstered with hemp fabric and interior parts made from sweet potato-derived PLA reinforced with sugarcane bagasse was the springboard for the eventual implementation of biomaterials in the Toyota Raum later on in 2003 [133]. Similarly, to create awareness for an environmentally sustainable industry, Ford automotive introduced model U concept car in the 2003 Washington D.C. auto show. This had William McDonough [134], the project design consultant noting that "it's a vision for cars that are made entirely of materials with positive human and environmental impacts; biological and technical nutrients made and assembled so they can be separated when the car is disassembled, and returned to the soil or to industry." U.K.-based Lotus car showcased Lotus Eco Elise green technology at the British Motor Show in 2008 in London featuring a bioplastics body and interior components made from sweet potatoes and sugarcane. This was aimed at making a statement on the use of sustainable materials and cleaner manufacturing processes to achieve weight and carbon miles reduction [135]. Renault has been developing a series of BioConcept cars for the race track with the first generation introduced in 2006 [66, 136]. Four Motors GmbH of Reutlingen, Germany were presented with the composites pioneer award for a racing car made almost entirely out of biocomposite materials with doors, mudguards, bonnet, bumpers, wings, and the boot lid made from natural fiber-reinforced plastics [137]. The design was based on a Mustang GT RTD and has evolved through several generations up to a Renault Mégane Trophy 09 [138] in which the natural fibers were combined with liquid bio plastic material (linseed oil acrylate) in a mold to produce parts that were capable of withstanding the motor sports track. Volkswagen Scirocco, a biopowered car, equipped with a rear hatch made of hemp and flax fibers was introduced on the German race track the Nurburgring as developing materials and rolling them out on the track, would stretch them to the limit in the process enabling the experts to ably predict their abilities. Also UPM Company partnered with the Helsinki University of Applied Sciences, the Finnish Funding Agency for Technology and Innovation to make the *Biofore* concept car which premiered at the 84th Geneva International motor show in March, 2014. The technology and construction methods used could reduce the car's weight by more than 15%. The researchers believe that the Biofore will serve as a technological showcase of what is possible and how materials and engineering methods can find their way into actual car making (Fig. 16).

### **CONCLUSIONS**

Demand for a better end of life disposal and light weight automotive parts as a gateway to easing on the automotive fuel consumption and thus cutting greenhouse gas emissions will continue to spur an increasing research on the feasibility of natural fiber-based composites in

automotives. With a flicker of hope so far manifested, car makers in the major industrial blocks; Europe, Japan, Korea, Brazil, and the United States are expected to keep up with the pursuit of these materials. The growing awareness amongst the end users, together with continued government and environmental bodies' involvement will help achieve more innovations in the coming future. These will then lead to a lasting solution to the issues of moisture absorptions (poor resin compatibility), sensitivity to ultra violet light, and inability to withstand long term exposure, impact and harsh road trail conditions; some of the main stumbling blocks to their fully fledged industrial application.

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