APPLICATIONS OF COMPOSITE MATERIALS WITH NATURAL FIBERS AND BIOPLASTIC MATRICES IN AUTOMOTIVE

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The paper focuses on summarizing the application possibilities of composite materials with natural reinforcements and bioplastic matrices in the automotive. The first section describes composite materials with natural reinforcements and the key reasons for their use. Within the text, the abbreviation NFRB-P is introduced to distinguish composite materials with a bioplastic matrix and natural reinforcement. The second section defines the individual components of NFRB-P with an explanation of their advantageous properties and limitations. The third section describes the application of NFRB-P in the automotive industry, focusing on a polylactic acid matrix in combination with flax, hemp, jute and kenaf fibers. In the concluding section, their applications in other domains are concisely outlined, predominantly targeting decorative components and general consumer products. Current published studies focus largely on the properties of NFRB-P materials; however, their practical industrial applications remain limited at present. The present study reflects their actual implementation in the sectors.

KEYWORDS

natural fiber, polylactic acid, bioplastic, composite material, natural reinforced plastics

1 INTRODUCTION

Composite materials reinforced with natural fibers play a significant role in advanced materials applications within the automotive industry, primarily by contributing to vehicle weight reduction, which in turn improves fuel efficiency and lowers the overall carbon footprint. Natural Fiber Reinforced Plastics (NFRP) are composites consisting of cellulose-based natural reinforcements (such as long/short fibers, or flour) combined with a conventional synthetic thermoplastic or thermosetting resin. Additives are incorporated to tailor the final properties of the composite, with selection dependent on the specific manufacturing process employed. In commercial contexts, NFRP composites are frequently marketed as bio-friendly, a designation that may lead consumers to mistakenly assume they are biodegradable. However, many NFRPs are not even recyclable, as the recycling of such composites is technically complex or entirely unfeasible. As a result, there is a growing trend among manufacturers to explore the use of degradable polymer matrices – bioplastics. To prevent ambiguity in material classification, we introduce the designation NFRB-P (Natural Fiber Reinforced Bio-Plastic) to specifically refer to composite materials with natural fiber reinforcements and a bioplastic matrix. The components and specifications of NFRB-P are outlined below.

2 COMPOSITION OF NFRB-P AND LIFE CYCLE ASSESSMENT OF PLA

2.1 Bioplastic (matrix)

The term bioplastic refers to a polymeric material that is either wholly or partially bio-based, yet not necessarily biodegradable; or, conversely, it may be both 100% bio-based and biodegradable. Examples of such materials include polylactic acid (PLA), polyhydroxyalkanoate (PHA), polybutylene succinate (PBS), polyhydroxybutyrate (PHB), and polyglycolide (PGA). Bioplastics are typically produced from renewable biomass sources such as vegetable oils and fats, corn starch, straw, wood chips, sawdust, cellulose, etc. It is important to note that the biodegradation of most bioplastics occurs effectively only in industrial composting facilities under controlled conditions (degradation time is specified by manufacturer). In contrast, domestic composting environments generally do not provide these conditions, especially in terms of thermal regulation and microbiological composition. Among the aforementioned materials, the most widely recognized bioplastic is polylactic acid (PLA), which was first synthesized by Wallace Carothers in 1932. PLA is an aliphatic polymer that may be semicrystalline or amorphous, derived from renewable sources, with a density of approximately 1.25 g·cm^{-3}. The physical properties of PLA are determined by factors such as molecular structure, chain orientation, and degree of crystallinity. Its mechanical performance is strongly influenced by molecular weight, with characteristics ranging between those of polystyrene (PS) and polyethylene terephthalate (PET). The incorporation of plasticizers enhances PLA's flexibility, tear resistance, and impact strength. PLA can exist in both semi-crystalline – PLLA (poly L-lactic acid)/PDLA (poly D-lactic acid) or a fully amorphous form – PDLLA (poly DL-lactic acid). The degree of crystallinity of PLA depends on the type and composition of the stereoisomers of lactic acid monomers and the polymer's thermal history. Crystallinity also affects the transition temperatures (including molecular weight and impurity content). From a technical perspective, the main limitation is the relatively low glass transition temperature (*Tg* = 55-60 °C). This temperature decreases with increasing D-isomer content. The melting temperature (*Tm*) of PLA ranges from 130 to 230 °C, depending on the PLA type. Owing to its good processability, PLA is commonly used to produce 3D printing filaments, with processing accompanied by a characteristic, non-toxic odor. However, PLA's chemical resistance is limited; it is readily soluble in solvents such as dioxane and chloroform [Engelberg 1991, Mohanty 2005, Auras 2010, Niaounakis 2015, Izdebska-Podsiadły 2022].



Figure 1. Luminy® PLA grades versus molecular weight: product of Total Energies Corbion company [Luminy 2025]

The global polylactic acid (PLA) market was valued at approximately USD 968.74 million in 2024 and is projected to expand more than fourfold by 2034. Major industrial producers include NatureWorks LLC (United States), TotalEnergies Corbion (Netherlands), BASF SE (Germany), Futerro (Belgium), Evonik Industries (Germany), and COFCO (China). PLA materials are classified into several series according to molecular weight and processing temperature. Under the trade name Luminy®, TotalEnergies Corbion offers an extensive portfolio of PLA grades specifically engineered for different processing technologies (see Figure 1 and Table 1) [Vink 2007, Polylactic acid market 2025, Ken research 2025, Swar 2026].

Type of Technology	Luminy® PLA grades
3D printing	L105/L130/LX530/LX175/LX975
Injection molding	L105/L130/LX530
Extrusion/Thermoforming	L175/LX575/LX930
Paper extrusion coating	LX530/LX175/LX930
Biaxial oriented film	LX575/LX175/LX975
Cast fiber extrusion	L175/LX575/LX975
Fiber spinning	L130/L175/LX530/LX175/LX930

Table 1. Application of Luminy® PLA for applications [Luminy 2025]

2.2 *Life Cycle Assessment of PLA*

Life Cycle Assessment (LCA) is a standardized analytical methodology used to quantify and evaluate the environmental impacts associated with a product over its entire life cycle from raw material extraction and manufacturing to utilization and end-of-life management. The LCA of PLA is typically structured into the following principal phases. During phase I – raw material acquisition and processing. PLA is predominantly derived from renewable biomass sources, most commonly sugarcane (*Saccharum officinarum*). Following harvesting and transport to the processing facility, carbohydrates contained in the biomass – primarily polysaccharides and simple sugars – are converted into lactic acid via microbial fermentation. Fermentation represents a chemically efficient, economically viable, and industrially standardized process capable of achieving high-purity lactic acid suitable for subsequent polymerization. Purification of the fermentation broth constitutes a critical step, ensuring the requisite monomer quality for polymer synthesis. The purified lactic acid is then cyclized to form lactide, which undergoes ring-opening polymerization to yield high–molecular-weight PLA. Material processing – phase II. Polylactic acid can be processed using a variety of conventional and advanced manufacturing techniques, including blow molding, blending, compounding, electrospinning, injection molding, casting, thermoforming, foaming, extrusion, and additive manufacturing (3D printing) [Farah 2016, Castro-Aguirre 2016]. According to [Keoleian 2012] the energy demand associated with producing 1 kg of PLA-based products varies considerably depending on the selected processing method. Extrusion requires approximately 2 $MJ \cdot kg^{-1}$ of electricity with a Mass Input Factor (MIF) of 1.01, whereas injection molding consumes around 7.2 $MJ \cdot kg^{-1}$ with an MIF of 0.95. Phase III – End-of-Life (EoL). The principal EoL options for bioplastics include recycling, incineration, industrial composting, and anaerobic digestion. Currently, most PLA products are designed for single-use applications with intended compostability. According to [ARN 2024], the degradation of PLA components is achievable under controlled industrial composting conditions specifically, at a temperature of 58 ± 2 °C, with appropriate pH, moisture, and microbial concentration within a period of 3-6 months. PLA is a recyclable material, identified with the recycling symbol 7 (other plastics), and can undergo both mechanical and chemical recycling. [Maga 2019] evaluated various PLA valorization strategies. In mechanical recycling, the resulting material exhibits properties (elastic modulus and impact strength) comparable to those of virgin PLA. In chemical recycling, it is necessary to ensure highly purified waste with respect to infusible contaminants.
[Chen 2024] compared the life-cycle carbon emissions of 1,000 units of single-use traditional products typically manufactured from polyethylene (PE) and polypropylene (PP) with those of equivalent biodegradable plastic products. The results indicate that the CO_2-equivalent emissions (eq/kg) associated with biodegradable plastics are 13.5-62.1% lower than those of traditional plastics. The study evaluated four phases of the product life cycle, spanning from raw material acquisition to EoL management. For biodegradable materials, multiple EoL scenarios were considered, including industrial composting, anaerobic digestion, and mechanical/chemical recycling, to capture the variability in environmental outcomes.

2.3 *Natural fibers (reinforcement)*

The term natural fibers (see Figure below) encompasses a broad spectrum of materials, which are generally classified according to their origin: plant-based (cellulose), animal-based (protein), and mineral-based (e.g. asbestos). Plant-derived fibers are further categorized depending on the part of the plant from which they are extracted – such as bast, leaf, seed, stem, or wood fibers. In the context of composite material production, natural fibers typically refer to agro-based fibers, including bast, leaf, seed, stem, and wood-derived fibers [Cheng 2012].

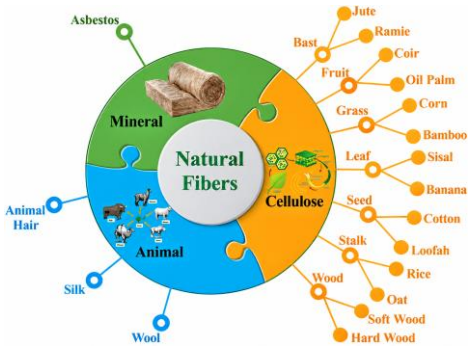


Figure 2. Classification of natural fibers [Elfaleh 2023]

Advantageous properties and limits of cellulose-based fibers [Hodzic 2014, Kim 2010]: Specified properties – cellulose fibers possess a relatively low density along with adequate stiffness and tensile strength. Numerous studies suggest that, in specific applications (e.g., automotive composites), natural fibers can serve as viable substitutes for glass fibers. These fibers are also economically advantageous, offering a lower-cost alternative to synthetic reinforcements, depending on the source and processing quality (see Figure 3 and Table 2). Recyclability and biodegradability – owing to their natural origin, cellulose fibers are inherently biodegradable. However, when incorporated into composite materials with synthetic polymer matrices, EoL processing and recyclability become considerably more complex and remain an open challenge. Health and safety – unlike glass fibers, which can cause respiratory irritation upon prolonged inhalation and may lead to skin irritation (itching, redness, etc.), natural fibers pose minimal health risks during handling and processing. Limitations – the principal drawbacks of cellulose fibers in composite applications include their low

thermal resistance (degradation typically begins at approximately 200 °C) and their hydrophilic nature, which can lead to moisture uptake and reduced dimensional and mechanical stability in humid environments.

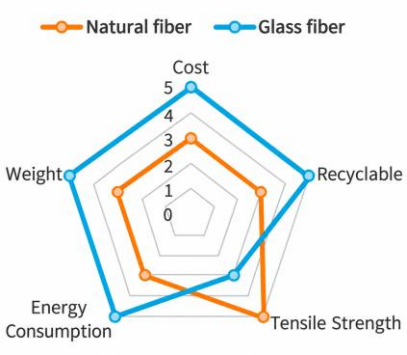


Figure 3. Classification of natural fibers (illustration of authors, data from [Samir 2022])

Fiber	Density (g·cm⁻³)	Elongation (%)	Tensile strength (MPa)	Young's modulus (GPa)
Flax	1.5	2.7-3.2	345-1035	27.6
Hemp	1.4	1.6	550-900	50
Sisal	1.3-1.5	2.0-2.9	507-955	9-28
Banana	0.8	2.0	161	8.5
Kapok	1.47	2.0-4.0	45-64	1.73-2.55
Cotton	1.5-1.6	7.0-8.0	287-597	5.5-12.6
Wood	–	4.4	25.8	2.23
E-glass*	2.6	1.8-3.2	3450	72.4

Table 2. Comparison of properties of selected fibers (natural and synthetic) [Srb 2018, Shahria 2019, Trivedi 2023, Stark 2003, Zhu 2009]

A major disadvantage of natural fibers is their hydrophilic character, which leads to insufficient interfacial adhesion between the composite phases. To mitigate these issues, fibers are typically modified using either physical or chemical methods. Physical modification techniques include stretching, calandering, thermotreatment, production of hybrid yarns, and plasma or corona discharge treatments. These approaches alter the surface and structural properties of the fibers while maintaining their intrinsic chemical composition. In chemical modification, coupling agents are applied to enhance interfacial adhesion. Interaction with the coupling agent reduces the number of free hydroxyl groups, thereby decreasing the hydrophilicity of the fiber. Common chemical treatments include alkali treatment (mercerization), silane treatment, acetone treatment, and the use of maleic anhydride-modified polypropylene or polyethylene as coupling agents [Bledzki 1999, Wang 2003, More 2022].

The introductory section of this article provides a concise overview of the constituent components of composites, while the subsequent chapter discusses the history of NFRB-P and explores their potential applications, with a particular focus on the automotive sector.

3 APPLICATION OF NFRB-P COMPOSITE MATERIALS IN AUTOMOTIVE

In the automotive sector, composite materials reinforced with natural fibers and combined with synthetic matrices are increasingly employed. This trend is evidenced by the growing number of publications in the field (see Figure 4), based on keyword searches in the Web of Science database for *composite with natural fibers in automotive industry*. However, it remains challenging to differentiate studies that specifically address composites based on bioplastic matrices. While some publications explicitly indicate the use of bio-based matrices in their titles, many others continue to use the generic designation NFRP, irrespective of the matrix origin.

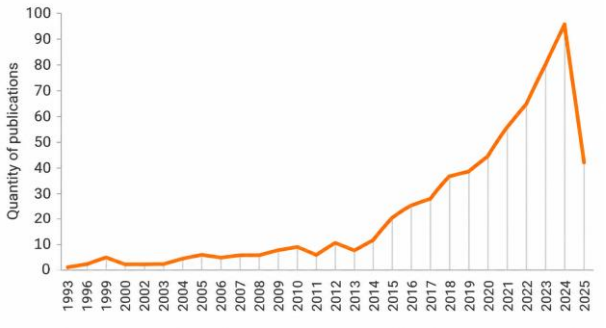


Figure 4. Quantity of publications in range 1993-2025 (the data presented are current as of June 2025)

Research dedicated to NFRB-P composites spans several key thematic areas [39–50]:

- Mechanical properties – strength and flexural behaviour: [Couture 2016] investigated the mechanical performance of a flax/PLA composite with low porosity (~4%). Incorporation of 44 wt% flax into the PLA matrix led to significant improvements in mechanical strength compared to neat PLA. [Sanivada 2020] examined a broad spectrum of properties in PLA/flax composites and benchmarked them against a flax-reinforced synthetic polymer. Results showed ~50% higher strength and a 2.5-fold increase in stiffness with 30 wt% fiber content. Microscopic analysis revealed interfacial adhesion issues between fiber and matrix – a recurring challenge in natural fiber composites. The authors concluded that production technologies developed for NFRPs with polypropylene matrices are also applicable to these bio-based systems, enhancing industrial feasibility. Similar findings were reported by [Motru 2020], who also assessed the effect of fiber surface treatment using silane. Interestingly, silane treatment resulted in reduced tensile strength.
- Fatigue behaviour – [Charca 2024] demonstrated the high fatigue resistance of flax/bioplastic composites, attributed to effective wetting of flax bundles by the matrix without the need for pre-treatment. Two analytical methods yielded the same fatigue limit: $\sigma_{\infty}=0.43\sigma_{ut}$ (σ_{ut} corresponds to the ultimate tensile strength).
- Resistance to moisture, biodegradation and biological attack – [Kumar 2010] investigated the effect of amphiphilic additives on the biodegradation of PLA/flax composites via soil burial tests. The presence of these additives accelerated decomposition and increased mass loss. [Atli 2018] studied hygroscopic behaviour in composites made from bioplastic and up to 30 wt% spruce sawdust, compostable under industrial conditions. Resistance to fungal and termite attack improved with increasing filler content. [Zouari 2023] evaluated the addition of biochar to PLA/hemp composites. A 10 wt% biochar addition significantly enhanced resistance to both white and brown rot and reduced mass loss. [Kumari 2021] focused on water absorption (WA) in PLA/sisal composites, with fiber contents ranging from 0-30 vol%. WA increased markedly with fiber content due to the cellulose-rich surface area.
- Resistance to UV radiation and flammability – [Pornwannchai 2008] assessed flame retardant efficiency in flax/PLA composites produced from blended fabrics.

Although flame retardants were effective, they led to degradation of mechanical properties, likely due to the pH of the retardant. Organophosphonate-based flame retardants with high nitrogen and phosphorus content were the most effective**.** [Gonzalez-Lopez 2020] compared the UV resistance of neat PLA and PLA-based biocomposites. Findings were inconclusive, but it was observed that lignin in the fibers accelerated photodegradation under short-term exposure. The authors hypothesized that this could be mitigated by improving fiber-matrix interfacial bonding using appropriate additives, though the potential toxicity of such additives remains a concern.

- The modification (chemical and physical treatment) – [Foruzanmehr 2016] demonstrated that grafting treatments of flax fibers in PLA composites significantly improved interfacial adhesion, leading to a threefold increase in impact strength. Similarly, [Georgiopoulos 2016] applied nanocoating techniques, achieving enhancements in tensile strength (+6%), modulus of elasticity (+13%), and interlaminar shear strength (+20%), alongside improved moisture resistance.

The current literature indicates a predominant research focus on NFRB-P composites comprising a PLA matrix reinforced with flax fibers. While other natural fibers such as hemp, jute, and kenaf are also investigated in combination with PLA matrices, their industrial deployment remains limited. An overview of early initiatives to introduce bio-composites into production, along with current applications, is presented below [Plackett 2003, Behera 2012, Murariu 2016].

A pioneering figure in the development of composite materials with natural reinforcements and bio-based polymers in the automotive sector was Henry Ford (1863–1947). In 1941, during the Dearborn Days Festival (Michigan), Ford unveiled the prototype of the so-called *Soybean Car*. Developed under the direction of Lowell Overly with contributions from botanist George Washington Carver, the vehicle incorporated agricultural-based polymeric materials including paper and soybean resin for several body components. This approach reduced the total vehicle weight from approximately 907 kg to 454 kg compared to a standard steel car. The Soybean Car was designed to operate on alternative fuels, including hemp-derived fuel and ethanol produced from agricultural waste, with an estimated engine power of 60 horsepower. Ford's motivation stemmed from multiple factors, including wartime metal shortages and the ambition to create a vehicle capable of enhanced energy absorption in collisions. It was hypothesized that polymer-based components in critical deformation zones would improve impact performance relative to conventional metal-bodied vehicles. However, the onset of the Second World War curtailed the American automotive industry, and mass production of the Soybean Car never materialized. The exact composition of the bio-composite materials used in the vehicle remains uncertain, with varying accounts reported in the literature [Smits 2016, Mitalova 2023, Cockpit 2024].

In 2017, the Lina electric vehicle, developed by a student team from Eindhoven University of Technology, was presented at the Shell Eco-marathon (see Figure 5). The vehicle featured a chassis constructed from a composite material reinforced with flax fibers embedded in a PLA matrix sourced from NatureWorks. The structural design employed a sandwich panel configuration, consisting of a PLA-based honeycomb core produced from a biodegradable resin derived from sugar beet (positioned between two flax fiber composite face sheets). The PLA honeycomb core was fabricated using ThermHex technology, developed by EconCore. This design provides high stiffness and strength at a relatively low weight, demonstrating mechanical performance comparable to conventional fiberglass composites [Pye 2017, Econcore 2026].



Figure 5. Electrical automobile – LINA and honeycomb structure from PLA for core of composite material [Pye 2017]



Figure 6. Technical textile from flax and composite material – incorporated into the interior of a car [Porcher industries 2023, Stubbins 2022]

In 2022, the French company Porcher Industries introduced a range of flax fiber textiles to the market, designed for thermo-compression and injection molding processes. PLA was cited as one of the potential matrices, alongside conventional thermoplastics such as polypropylene and polyamide 11. The resulting composite prepregs are intended for automotive interior applications, including dashboards, door reinforcements, and decorative panels. The visual characteristics of the reinforcements can be customized, with options including flax fiber dyeing and variation in thread thickness. Porcher Industries collaborates with Terre de Lin (Saint-Pierre-le-Viger, France), a global leader in the development and production of flax fiber rovings, see Figure 6 [Stubbins 2022, Porcher industries 2023].

The British company Sonichem specializes in processing low-carbon raw materials, such as lignin, the world's second most abundant biopolymer, to produce renewable plastics and plastic matrix composites for automotive applications. Sonichem has patented an ultrasound-assisted technology for fractionating woody biomass into hemicellulose sugars, microcrystalline cellulose, and low molecular weight lignin. The lignin is extracted from sawdust, a by-product of Sitka spruce logging in the UK. The resulting lignin is highly soluble in organic solvents, sulfur-free, and exhibits resistance to oxidative degradation and ultraviolet radiation. Sonichem is a leading partner in the CARMA project (Carbon-neutral Agroforestry-derived Resins to Materials for Automotive applications), which aims to develop carbon-neutral resins from agroforestry feedstocks for automotive materials. The project is funded by Innovate UK under the *Resource Efficiency for Materials and Manufacturing* competition, with a grant covering 70% of the estimated project costs [Sonichem 2024].

In a related initiative, the SUSPENS project, launched in 2023, focuses on synthesizing bio-based resins with potential reinforcement from cellulose fibers, lignin-derived carbon fibers, or recycled carbon fibers. Project lead Mehdino Merina notes that up to 95% of the bio-resins can be synthesized from flax, oilseed rape, castor oil, or algae. The materials are

intended for three key sectors: automotive, aerospace, and leisure marine. Performance will be demonstrated through three representative prototypes: an automotive battery housing, a leisure boat hull, and an aerodynamic winglet. The project's overarching goal is the sustainable production and recycling of composites, aiming for significantly reduced CO_2 emissions across their life cycle [Suspens 2025, Stubbins 2023].
A hemp fiber-reinforced PLA composite is expected to be patented soon, resulting from a collaboration between researchers and students from the University of Indonesia and the University of Paris Nanterre. The material targets the automotive industry, particularly body panels and structural components. Compared to conventional prepregs made with synthetic fibers, the hemp/PLA composite offers lower weight and a more cost-effective alternative. A secondary objective of the project is to support local hemp producers in Indonesia by establishing supply agreements with French research laboratories [Wood 2024].

4 OTHER APPLICATIONS OF NFRB-P

The company Sulapac Ltd. (Finland) is engaged in the development of recyclable materials. The portfolio also includes materials made of biodegradable polymers with wood fibers – a by-product of the wood industry. One of them is Sulapac Flow 1.7 (suitable for both in-line thermoforming and offline processes where sheets are formed separately) applicable to produce disposable packaging, containers, trays, etc. The material contains 20% wood-based content + PLA. It is completely bio-degradable in industrial compost after 12 weeks, in accordance with the EN 13432 standard, which stipulates that after sieving the compost through a sieve with a mesh size of 2 mm, the residual fraction must not exceed 10% of the original dry weight – see demonstration of decomposition in Figure 7. It can replace traditional PET/PS/PP plastics, compared to which it requires lower thermoforming temperatures → which ultimately can lead to energy savings of up to 20% [Nylanden 2025, Stubbins 2024, Sulapac 2026].
The company KCARBON (South Korea) in cooperation with the Korea Institute of Science Technology developed a biocomposite comprising lyocell fiber, PLA and wood – primarily as a replacement for plywood. Through testing, they were able to obtain several times higher values of the modulus of elasticity, tensile strength and impact toughness (compared to plywood). Lyocell is a continuous fiber obtained from wood pulp, made from ecological/recycled solvents, spun into endless fibers. It is typically applied in the production of textiles. The fiber is strong, highly durable, hygroscopic, biodegradable under appropriate conditions within 30 days. The lyocell/PLA material in the form of a prepreg was subsequently interleaved with thin layers of birch veneer – by pressing. The pressed material was applied in the production of furniture [Gardiner 2023].



Figure 7. Decorative elements made of material manufactured by Sulapac, demonstrating decomposition over time [Stubbins 2024, Sulapac 2026]

5 CONCLUSIONS

The weight of vehicles significantly affects fuel consumption and has a direct impact on the amount of CO_2 emissions released into the atmosphere. Similarly, the technologies for producing individual car components are also important in the vehicle manufacturing process, with a direct impact on energy consumption. Car manufacturers have primarily achieved a reduction in vehicle weight by applying plastics, which are currently not a universal solution. In relation to environ-mental friendliness, emphasis is increasingly placed on the selection of materials that are recyclable or compostable under industrial conditions. Several research studies and projects focus on the development and evaluation of the properties of NFRB-P materials (primarily with a PLA matrix) reinforced with various types of natural fibers. The use of these materials has the potential to reduce environmental pollution, production costs, and energy consumption, depending on the specific material composition, manufacturing process, and end-of-life management. Furthermore, the use of plant-based reinforcements may support local agriculture and contribute to the development of regional economies. The application of NFRB-P composites is possible in various sectors – from the food industry (packaging) to the automotive industry (dashboards, door reinforcements, etc.). Currently, areas are being identified where they can effectively replace conventional materials with a positive impact on the environment. In connection with the circular economy (LCA), there is a transition from the standard *make-use-dispose* model to a more sustainable system. This approach emphasizes waste minimization, efficient use of raw materials, and maximizing the value of products throughout their entire life cycle.

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