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Bioplastics from Waste Biomass: Paving the Way for a Sustainable Future

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Abstract: ***Bioplastics originating from waste biomass present a viable remedy to the environmental dilemmas associated with traditional plastics, thereby reducing dependency on fossil fuels and mitigating carbon emissions. This review investigates the utilization of diverse waste biomass sources, encompassing agricultural residues, food waste, industrial by-products, municipal solid waste, and forest biomass residues, in the synthesis of bioplastics. Technological innovations in feedstock pretreatment, bioconversion methodologies, and polymerization techniques have markedly enhanced the efficiency and material characteristics of bioplastics, establishing them as formidable alternatives to petroleum-derived plastics. Notwithstanding these advancements, obstacles such as feedstock inconsistency, scalability issues, technological limitations, and consumer acceptance persistently impede the extensive adoption of bioplastics. The ecological advantages of bioplastics, particularly concerning their diminished carbon footprint and potential for biodegradability, are underscored through life cycle assessments (LCAs). Government policies, the increasing market demand for sustainable products, and advancements in emerging technologies, including synthetic biology and AI-enhanced process optimization, are propelling the commercialization of bioplastics derived from waste biomass. The incorporation of bioplastics within a circular economy framework, coupled with considerations for long-term sustainability, positions them as a pivotal element in fostering a more sustainable and environmentally friendly future. This review offers a thorough examination of the present landscape, challenges, and future prospects of bioplastics production from waste biomass.***

Keywords: Bioplastics, Waste biomass, Environmental Pollution, Polylactic acid (PLA), Polyhydroxyalkanoates (PHA)

I. INTRODUCTION

Bioplastics represent a promising alternative to conventional petroleum-based plastics, offering environmental benefits through biodegradability and reduced carbon footprints [1]. Bioplastics differ significantly from traditional plastics in their chemical composition and environmental impact [2]. Traditional plastics, such as polyethylene and polypropylene, are derived from fossil fuels and consist of synthetic polymers, which contribute significantly to environmental degradation due to their non-biodegradable nature, with over 8 million tons entering oceans annually [3]. According to a report by Our World in Data (2021), global plastic production has increased from 2 million tons in 1950 to 367 million tons in 2020 [4]. Of this, over 300 million tons of plastic waste are generated annually, and only 9% of this waste is recycled [4]. Additionally, recent studies show that microplastics are now found in drinking water, food, and even in human blood [5], [6], [7]. These particles pose health risks, as they can accumulate in organs and potentially disrupt biological systems. It is estimated that by 2050 traditional or synthetic plastics could account for up to 15% of global carbon emissions if current trends continue[8]. On the other hand, bioplastics can be fully or partially bio-based, derived from renewable resources like starch, proteins, and polyhydroxyalkanoates (PHA) [9]. They are usually categorized into biodegradable polymers, such as polylactic acid (PLA) and polybutylene adipate terephthalate (PBAT) [10], as illustrated in Fig. 1.

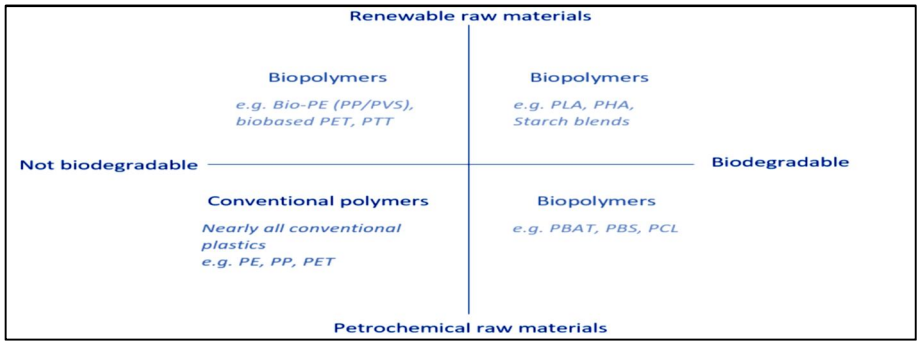

Fig. 1 Overview of the different types of bioplastics

Bioplastics derived from waste biomass sources present a sustainable alternative to conventional plastics, leveraging various agricultural, industrial by-products, municipal solid waste (MSW), and forest biomass residues [11]. The most promising sources include waste wood, corn stalks, microalgae, corncob residues, and fruit peels, each offering unique advantages [12]. It is estimated that the world generates around 5 billion tons of agricultural waste annually [13]. According to the Food and Agriculture Organization (FAO), approximately 1.3 billion tons of food waste is generated globally every year, this includes organic waste from households, restaurants, and food industries [14]. The forest industry generates about 1.2 billion tons of woody biomass residues, including bark, sawdust, and wood chips [15]. On a global scale, about 2.01 billion tons of MSW is generated annually, with organic waste biomass accounting for approximately 46%, which includes food scraps, yard trimmings, and paper products [16]. Industrial sectors like sugar production, palm oil, and paper mills contribute significantly to biomass waste. For example, the sugar industry generates about 279 million tons of bagasse (sugarcane waste) each year globally [17]. Bioplastics derived from waste biomass can decrease greenhouse gas emissions by 35% to 80% compared to conventional plastics [18]. In addition, fully biomass-derived films have demonstrated favorable degradation rates, contributing to reduced plastic pollution [19]. The use of waste biomass as a feedstock for bioplastics production presents significant environmental benefits compared to traditional fossil fuel-based methods [20]. This approach not only reduces reliance on non-renewable resources but also mitigates pollution and waste management issues [21].

The significance of bioplastics obtained from waste biomass is vital in the global initiative to mitigate plastic pollution and reduce reliance on fossil fuels [22]. Bioplastics, particularly those produced from waste biomass, present a sustainable alternative. For example, enterprises such as NatureWorks are manufacturing polylactic acid (PLA) bioplastics utilizing agricultural waste, thereby mitigating landfill accumulation and carbon emissions [23]. Furthermore, international initiatives, including the European Union's Circular Economy Action Plan, highlight the shift towards sustainable materials, which propels innovation in waste-derived bioplastics [24]. This methodology not only reduces environmental repercussions but also enhances the value of waste, in accordance with the tenets of a circular economy.

II. TYPES OF WASTE BIOMASS FOR BIOPLASTICS PRODUCTION

Recent studies demonstrate that various waste biomass sources can yield bioplastics with desirable mechanical and physical characteristics.

A. Agricultural Residues

Crop residues, such as corn stover, rice husk, and wheat straw, have gained attention as sustainable feedstocks for bioplastic production [25]. These residues are agricultural by-products that would otherwise go to waste or be burned, contributing to environmental pollution. Corn stover which consists of leaves, stalks, and cobs left after harvesting corn, rice husk, and wheat straw consisting of stems and leaves left after wheat harvesting are valuable agricultural residues for bio-based polyhydroxyalkanoates (PHA) and polylactic acid (PLA) production [26]. These agricultural residues are rich in cellulose, hemicellulose, and lignin, which can be transformed into biopolymers like PLA [26]. Companies like NatureWorks have been focusing on PLA production using corn-based feedstocks [27]. Research from Iowa State University is exploring ways to improve the efficiency of converting corn stover into PLA, enhancing yield and reducing production costs [28]. According to Brites et al., (2024), the Indian Institute of Technology (IIT) has developed bioplastic films from rice husk that are both biodegradable and cost-effective [29]. Rice husk is rich in lignocellulose, a complex of cellulose, hemicellulose, and lignin, making it a valuable resource for producing bio-based plastics. According to Sachan et al., (2024), in Europe, wheat straw has been utilized by companies like Bio-on to produce PHA [30]. Additionally, researchers at the University of York are working on converting wheat straw into sustainable biocomposite materials for packaging and automotive parts [31].

B. Food Waste

Food waste, including fruit peels and vegetable scraps, is emerging as a promising feedstock for bioplastic production. Fruit peels and vegetable scraps are rich in cellulose, starch, pectin, chitin, chitosan, and lignin which can be converted into biopolymers [32]. Orange peels rich in cellulose have been utilized to create biodegradable plastic films that are transparent, flexible, and suitable for packaging [33]. Cellulose is extracted from orange peels and converted into cellulose acetate or other bio-based polymers. Potato peels rich in starch can be converted into thermoplastic starch (TPS), which is a biodegradable material widely used in packaging, disposable cutlery, and agricultural films and when combined with other biopolymers like PLA, it improves the material's mechanical properties [34].

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Apple peels rich in pectin are used to produce bioplastic with good film-forming capabilities which can be used in food packaging [35]. Mushroom waste is being explored as a source of chitosan for bioplastic, when deacetylated, chitin becomes chitosan, a biopolymer used to create biodegradable films and coatings [36], chitosan has antimicrobial properties, making it ideal for food packaging. Tomato skins and other vegetable waste rich in lignin content can be used as a natural binder and reinforcing agent in bioplastic [37].

C. Industrial By-products

Industrial by-products such as glycerol, lignin, and cellulose are increasingly being used as feedstocks in bioplastic production, contributing to more sustainable manufacturing processes. According to, Bio-on, an Italian company, glycerol can be used as a plasticizer in the production of polyhydroxyalkanoates (PHAs) and biodegradable polyesters [38]. Glycerol is a by-product of biodiesel production and oleochemical industries. It is abundant and inexpensive due to the rise of biodiesel production globally. Similarly, According to Chung, (2021), researchers from the University of Delaware have developed a lignin-based bioplastic that is fully biodegradable [39]. Lignin is a by-product of the paper and pulp industry and is one of the most abundant natural polymers. According to Tomani, (2017) the LignoCity project, in Sweden, lignin is converted into value-added bioplastic for use in packaging materials, replacing petroleum-based plastics with more sustainable alternatives [40]. These lignin-based materials are highly resistant to UV radiation, making them suitable for outdoor applications. According to Gruter and van Aken, (2021), Avantium, a renewable chemicals company, has developed cellulose-based PEF (polyethylene furanoate) as a replacement for PET in plastic bottles [41], cellulose is the most abundant natural polymer, derived as a by-product from the paper, textile, and agricultural industries.

D. Municipal Solid Waste (MSW)

The organic fraction of Municipal Solid Waste (MSW), which includes kitchen waste (food scraps, vegetable peels, fruit wastes) and yard trimmings (grass clippings, leaves, branches), offers a valuable feedstock for producing bioplastic. Yard trimmings, rich in cellulose, have been used in processes where lignocellulosic material is hydrolyzed to produce fermentable sugars, which are then converted into biodegradable plastics like PLA [42]. According to Ventura and Venturs, (2024), a project in Finand is using yard trimmings to produce polyhydroxybutyrate (PHB), a type of PHA bioplastic [43].

E. Forest biomass residues

Forest biomass residues, including bark, sawdust, and wood chips, are renewable and abundant sources of lignocellulosic material that can be used in bioplastic production [44]. This biomass is rich in lignin, cellulose, hemicellulose, and extractives (resins and tannins). Lignin found in bark, sawdust, and wood chips, can be extracted and used as a reinforcing agent or even chemically modified for use in bioplastic [45]. Cellulose and Hemicellulose are abundant in wood biomass, they can be broken down into sugars that are fermented into bio-based monomers, which are then polymerized into biodegradable plastics like PLA or PHA [46]. Extractives such as resins, tannins, and other chemical compounds found in bark and wood can be used as additives or precursors in bioplastic formulations [47].

III. TECHNOLOGICAL ADVANCEMENTS IN BIOPLASTICS PRODUCTION FROM WASTE BIOMASS

Technological advancements in bioplastics production from waste biomass have significantly improved the efficiency, sustainability, and scalability of bioplastics as an alternative to petroleum-based plastics.

A. Novel feedstock pretreatment techniques

Before converting waste biomass into bioplastics, it must be pretreated to break down complex lignocellulosic structures, such as cellulose, hemicellulose, and lignin, into simpler components. Novel pretreatment techniques for converting complex waste biomass into simpler components are delineated in Table 1.

Table I Novel pretreatment methodologies aimed at the transformation of complex waste biomass into simpler components.

Pretreatment Technology	Description	Advantages	Feedstock Examples	Recent Advancements	Example Application	References
Steam Explosion	Uses high-pressure steam	Energy-efficient and	Corn stover,	More effective at releasing	Utilizes steam explosion for	[48]

	to break down the lignocellulosic structure of biomass.	scalable for industrial use	wood chips, wheat straw	fermentable sugars. Lower energy consumption	breaking down straw into sugars for bioplastics production.	
Ionic Liquids	Advanced solvents are used to dissolve biomass and extract cellulose.	High-efficiency and recyclable solvents	Corn stover, rice husks, and other agricultural residues	Reduced waste. Sustainable recycling of solvents	Ionic liquids are used to dissolve lignocellulosic biomass into simple sugars for biopolymer synthesis.	[49]
Deep Eutectic Solvents (DES)	A new class of green solvents with low toxicity and environmental impact is used to break down biomass.	Environmentally friendly and low in toxicity	Wood chips, agricultural residues, forest biomass	Improved lignocellulosic breakdown. Lower ecological impact compared to ionic liquids	DES is applied in the pretreatment of forest biomass for sustainable bioplastics production.	[50]

B. Advancement in bioconversion technologies

Bioconversion, through enzymatic hydrolysis and microbial fermentation, is at the heart of bioplastics production from waste biomass [51], [52]. New developments in these areas focus on increasing efficiency and yield while reducing costs.

1) Recent advancements in microbial fermentation

Microbial fermentation uses microorganisms (bacteria, yeast, and fungi) to break down biomass and produce bio-based monomers like lactic acid, which are used to synthesize polymers such as Polylactic Acid (PLA), or directly produce Polyhydroxyalkanoates (PHA) [51]. Recent developments in the microbial fermentation of waste biomass utilized in the synthesis of bioplastics are delineated in Table 2.

Table II Recent advancements in microbial fermentation of waste biomass utilized in the synthesis of bioplastics

Microorganism	Biomass Feedstock	Product	Advancement	References
Lactobacillus spp.	Food waste, agricultural residues	Lactic Acid (for PLA)	Improved fermentation efficiency and yield	[53]
Cupriavidus necator	Waste glycerol, forest residues	Polyhydroxybutyrate (PHB)	Genetic engineering for enhanced PHB production	[54]
Pseudomonas putida	Lignocellulosic biomass	Polyhydroxyalkanoates (PHA)	The strain was engineered to convert sugars from food waste into PHA at a yield of 45 g/L.	[54]

2) Recent advancements in enzymatic hydrolysis

Enzymatic hydrolysis involves breaking down complex carbohydrates (like cellulose and hemicellulose) in biomass into simple sugars, which can then be fermented or chemically processed into monomers like lactic acid for bioplastics [52]. Recent developments in the enzymatic hydrolysis of waste biomass utilized in the synthesis of bioplastics are delineated in Table 3.

Table III Recent advancements in enzymatic hydrolysis of waste biomass utilized in the synthesis of bioplastics

Enzyme	Biomass Feedstock	Monomer/Polymer	Advancement	References
Cellulases	Agricultural residues (corn stover, wheat straw)	Glucose (for PLA)	Enhanced enzyme efficiency at lower temperatures	[55]

Xylanases	Food waste, forest residues	Xylose (for PHA)	Cost-effective enzyme production methods	[56]
Laccases	Lignin-rich biomass (bark, wood chips)	Lignin derivatives (for biocomposites)	Improved lignin breakdown and valorization	[57]

a) Enzyme Optimization

- Thermostable Enzymes: These enzymes can operate at higher temperatures, speeding up the hydrolysis of lignocellulosic biomass, reducing energy costs, and increasing sugar yields [58].
- Cocktail Enzymes: New enzyme mixtures, such as those combining cellulases, hemicellulases, and laccases, improve the breakdown of biomass by targeting multiple components simultaneously [59].
- Efficiency enhancements in the process of new enzyme-cocktail-based hydrolysis for the production of bioplastics are delineated in Table 4.

Table IV Efficiency improvements in new enzyme-cocktail based hydrolysis for bioplastics production

Feedstock	Traditional Hydrolysis Yield	New Enzyme Cocktail Yield	References
Corn Stover	60%	85%	[60]
Wheat Straw	55%	80%	[61]
Rice Husk	50%	78%	[62]

The process of microbial fermentation, which involves the metabolic activities of microorganisms such as bacteria and yeast, operates through the anaerobic breakdown of organic substrates, thereby producing energy-rich compounds like ethanol and organic acids, while enzymatic hydrolysis entails the utilization of specific enzymes to catalyze the degradation of complex polysaccharides into simpler sugars, which can subsequently be fermented or further processed into desired end products. A detailed examination and analysis of the contrasting methodologies of microbial fermentation and enzymatic hydrolysis reveal significant differences in their mechanisms, efficiencies, and overall applications in the conversion of biomass into valuable biofuels and bioproducts (Table 5).

Table V Comparison of Microbial Fermentation and Enzymatic Hydrolysis in Bioconversion

Parameter	Microbial Fermentation	Enzymatic Hydrolysis	References
Feedstock Type	Organic waste, sugars	Lignocellulosic biomass	[63]
Product Yield (g/L)	30-50 g/L	20-40 g/L	
Process Temperature (°C)	30-40°C	50-60°C	
Primary Product	PLA, PHA	Monomers for PLA, PHA	
Environmental Impact	Low CO_2 emissions	Moderate, due to energy input	
Economic Feasibility	High for sugars-based feedstock	High with pretreatment improvements	

3) Combined Bioconversion Techniques

Combining enzymatic hydrolysis with microbial fermentation maximizes the efficiency of converting waste biomass into valuable monomers or polymers for bioplastics. In this process, lignocellulosic biomass is first hydrolyzed using enzymes, and the resulting sugars are fermented by microorganisms to produce lactic acid or PHAs [64]. Combining both processes can increase the overall efficiency of the bioconversion process, as delineated in Table 6.

Table VI A comparative analysis of independent enzymatic hydrolysis and independent microbial fermentation versus the integrated approach of enzymatic hydrolysis coupled with microbial fermentation

Bioconversion Technique	Description	Key Steps	Efficiency	Advantages	Example Application	References
Standalone Enzymatic Hydrolysis	Enzymes break down lignocellulosic biomass into simple sugars (e.g., glucose, xylose).	Biomass is pretreated and then. Enzymes hydrolyze cellulose into sugars.	Moderate	Simple process and suitable for various feedstocks	Lactic acid production from cellulose using cellulase enzymes.	[52]

Standalone Microbial Fermentation	Microorganisms convert sugars (from biomass) into monomers such as lactic acid or PHAs.	Sugars are fermented by microbes into bioplastics precursors	Moderate	Direct fermentation and flexible with microbial strains	Pseudomonas putida used to ferment sugars into PHAs for bioplastics.	[51]
Combined Enzymatic Hydrolysis and Microbial Fermentation	Enzymes hydrolyze biomass to sugars, followed by microbial fermentation of these sugars into bioplastic precursors like lactic acid or PHAs.	Biomass is hydrolyzed by enzymes and then microbes ferment the resulting sugars into valuable polymers.	High	Higher yield, more efficient conversion, and reduced waste	Clariant's Sunliquid Process integrates enzymatic hydrolysis with microbial fermentation to produce lactic acid for bioplastics from agricultural waste.	[64]

C. Recent advancements in polymerization techniques

Converting monomers, such as lactic acid or sugar-derived molecules, into polymers is a critical step in bioplastics production [53]. Recent advancements focus on improving polymer quality, material properties, and energy efficiency (Table 7).

Table VII Recent advancements in polymerization techniques for converting monomers into polymers for bioplastics production

Polymerization Technology	Description	Recent Advancements	Advantages	Example Application	References
PLA (Polylactic Acid)	Bio-based polyester is produced from lactic acid, derived from renewable resources like corn starch or sugarcane.	Ring-Opening Polymerization (ROP): Improves molecular weight and thermal properties, making PLA suitable for high-performance applications like packaging and 3D printing.	Improved mechanical strength, better heat resistance, and suitable for diverse applications	NatureWorks developed low-energy polymerization methods for producing high-purity PLA, enhancing clarity and strength for food packaging.	[65]
PHA (Polyhydroxyalkanoates)	Biodegradable polyester is produced inside microbial cells using engineered microbes to convert sugars into PHA granules.	Engineered microbes produce PHA directly within cells. Properties similar to polypropylene (PP).	Biodegradable, similar properties to petroleum-based plastics (e.g., PP), and suitable for single-use packaging.	Danimer Scientific uses microbial fermentation to produce PHA for bioplastics, offering an eco-friendly alternative to traditional plastics.	[66]
Biocatalysts	Bio-based catalysts	Reduced	Greener	MetGen	[67]

	are used in polymerization, offering high selectivity and operating under mild conditions.	environmental footprint. Lower energy requirements. Increased efficiency in polymerization reactions	production processes and reduced toxic by-products	develops biocatalysts to improve the polymerization of bioplastics like PLA and PHA, enhancing their sustainability.	
Metal-Free Catalysts	Organic, metal-free catalysts that polymerize bioplastics without the risk of contamination from heavy metals.	Focused on greener, non-metal catalysts. Improved purity of bioplastics	Reduced contamination risks and environmentally friendly	Research in Metal-Free Catalysis has improved the safety and sustainability of bioplastics production, particularly in medical and food applications.	[68]

D. Recent material enhancement and additive technologies

Bioplastics have traditionally struggled with performance issues, such as mechanical strength, barrier properties, and thermal stability. New technologies are addressing these challenges by developing bio-based additives, composites, and biocomposites [69]. Recent material enhancement and additive technologies are delineated in Table 8.

Table VIII Recent material enhancement and additive technologies for bioplastics production

Technology	Description	Recent Advancements	Advantages	Example Application	References
Nanocellulose Additives	Nanocellulose derived from waste biomass is used as a reinforcing agent to improve mechanical properties.	Improves mechanical strength and barrier properties of bioplastics. Derived from renewable sources	Increased strength, better barrier properties, and renewable source	Nanocellulose-reinforced PLA improves packaging materials, making them stronger and more durable.	[70]
Nanosilver and Nanoclay	Used in bioplastic films to enhance antimicrobial properties and shelf life in packaging applications.	Nanosilver imparts antimicrobial properties. Nanoclay enhances barrier properties.	Improved shelf life, antimicrobial features, and enhanced food safety	Food packaging films reinforced with nanosilver and nano clay to preserve the freshness and safety of food products.	[71]
Lignin-based Composites	Lignin from forest biomass is blended with biopolymers like PLA and PHA for stronger, UV-resistant biocomposites.	Lignin enhances the strength and UV resistance of biocomposites	Increased strength, UV resistance, and eco-friendly alternative	Lignin-based PLA composites are developed for durable and UV-resistant packaging and outdoor materials.	[72]
Fiber-reinforced Bioplastics	Agricultural waste fibers	Improved heat resistance and	Stronger bioplastics,	Cellulose nanofibers from	[73]

	(e.g., wheat straw, rice husk) are used to reinforce bioplastics like PLA and PHA.	mechanical durability	increased heat tolerance, and sustainable use of waste	wheat straw are used in automotive bioplastic components to enhance strength and stability.	

IV. ENVIRONMENTAL IMPACT OF BIOPLASTICS FROM WASTE BIOMASS

The environmental impact of bioplastics from waste biomass offers significant advantages over conventional, petroleum-based plastics, particularly in areas such as carbon footprint reduction, biodegradability, and waste management [74].

A. Life Cycle Assessment (LCA) of bioplastics

Life Cycle Assessment (LCA) is a crucial tool for evaluating the environmental performance of bioplastics produced from waste biomass. By comparing the entire lifecycle from raw material extraction, processing, and use, to disposal bioplastics show significant advantages over conventional petroleum-based plastics [75]. LCA studies generally report lower carbon footprints for bioplastics from waste biomass. Ali et al., (2023), found that PLA (Polylactic Acid) produced from agricultural waste emits up to 70% less CO2 compared to conventional plastics like polyethylene or polypropylene [76]. Since bioplastics capture CO_2 during the biomass growth phase, their net greenhouse gas emissions are significantly reduced. Bioplastics from waste biomass tend to require less energy in production. According to Morris and Hicks (2022), comparing PHA (Polyhydroxyalkanoates) from food waste to traditional polypropylene showed a 25% reduction in energy usage during production due to lower process temperatures and renewable feedstock [77]. Since bioplastics are derived from renewable, often waste, feedstocks, their production can help reduce overall waste generation. Furthermore, producing PLA from corn stover or wheat straw repurposes agricultural residues that would otherwise be discarded, significantly cutting down on waste that would otherwise contribute to landfills or be incinerated [78].

B. Biodegradability and Compostability of bioplastics

Bioplastics, especially those derived from waste biomass such as PLA, PHA, and starch-based plastics, exhibit different degrees of biodegradability depending on environmental conditions. Biodegradable plastics like PLA and PHA break down more readily in soil environments compared to conventional plastics. PLA, for example, can degrade in a few months to a year under industrial composting conditions, but it may take longer in natural soil environments due to cooler temperatures [79]. PHA biodegrades faster than PLA in soil and marine environments, often within 3–6 months under optimal conditions. PHA is considered marine biodegradable, breaking down in oceanic conditions within months. In contrast, PLA is not designed for marine degradation and may persist longer in such environments [80]. According to Lackner et al., (2023), noted that PHA bioplastics in seawater showed 90% degradation within six months, whereas PLA showed minimal degradation over the same period [81]. Bioplastics certified as compostable (e.g., PLA, PHA) can degrade in industrial composting facilities within a few weeks to months [82]. However, their compostability in home composting systems is slower, and not all bioplastics are suitable for such conditions [83]. According to Fogašová et al., (2022), compostable packaging made from PLA was found to decompose fully in industrial facilities in under 12 weeks [84].

C. Impact on Waste Management Systems and Landfills

The widespread adoption of bioplastics from waste biomass has the potential to significantly alter existing waste management infrastructures. The shift from traditional plastics to bioplastics introduces new challenges and opportunities. While bioplastics are recyclable, they require dedicated sorting and processing facilities to avoid contamination of traditional plastic recycling streams. PLA, for instance, is recyclable but needs to be separated from conventional plastics like PET to ensure proper recycling [85]. A lack of infrastructure for sorting and recycling bioplastics could result in higher contamination rates, complicating overall waste management. However, the compostability of bioplastics offers a solution for organic waste disposal, cities with industrial composting facilities can divert compostable bioplastics from landfills, reducing methane emissions associated with traditional waste [86]. In regions without industrial composting facilities, bioplastics may end up in landfills, reducing their environmental benefits. Bioplastics in landfills may still release some greenhouse gases if they degrade anaerobically [87]. However, their overall emissions are significantly lower compared to conventional plastics. According to Afshar et al., (2024), bio-based PHA and PLA suggested that their adoption could reduce the volume of waste going to incineration by 15-20%, lowering both air pollution and energy consumption in waste-to-energy plants [88].

V. MARKET POTENTIAL AND ECONOMIC VIABILITY OF BIOPLASTICS FROM WASTE BIOMASS

As of 2023, the global bioplastics market is valued at approximately USD 18 billion [89]. The market for bioplastics is expanding due to increased consumer and regulatory demand for sustainable alternatives to conventional plastics. The bioplastics market is projected to grow at a compound annual growth rate (CAGR) of around 15-20% over the next five years [89]. By 2028, the market size is expected to reach approximately USD 40 billion [90]. This growth is driven by rising environmental concerns, regulatory support, and technological advancements in bioplastics production. The push for reducing plastic pollution and the adoption of circular economy principles are driving the demand for bioplastics. Key sectors such as packaging, agriculture, and automotive are increasingly adopting bioplastics to meet sustainability goals.

A. Cost competitiveness of bioplastics from waste biomass

The economic challenges and opportunities associated with bioplastics production from waste biomass, focusing on raw material costs, production costs, and market pricing, are delineated in Table 9.

Table IX Cost analysis of bioplastics production from waste biomass

Aspect	Description	Current Challenges	Opportunities for Improvement	Recent Examples	References
Raw Material Costs	Bioplastics are often produced from feedstocks like corn, sugarcane, or waste biomass.	Higher costs for raw materials compared to fossil fuels. Feedstock variability	Utilizing waste biomass can lower raw material costs. Waste biomass is often less expensive or even free.	LanzaTech uses industrial waste gases to produce ethanol, reducing raw material costs compared to traditional feedstocks.	[91], [92]
Production Costs	The process of converting biomass into bioplastics involves several steps, including pretreatment and polymerization.	Energy-intensive processes. High capital costs for advanced technologies	Advancements in technology can reduce energy consumption. Streamlined processes can lower costs.	NatureWorks has invested in improving PLA production technology to reduce costs and increase efficiency.	[93], [94]
Market Pricing	The price of bioplastics often remains higher than conventional plastics due to production costs.	Higher prices can limit market adoption. Price volatility in raw materials	Economies of scale and technological advancements can reduce prices. Waste biomass can contribute to lower costs.	Danimer Scientific produces PHA at competitive prices, making it an attractive alternative to traditional plastics.	[95], [96]

B. Commercialization and industry adoption of bioplastics

The commercialization and industry adoption of bioplastics derived from waste biomass has been significantly advanced by several pioneering companies and their innovative approaches. These success stories illustrate how strategic partnerships and technological innovations can scale production and integrate bioplastics into mainstream markets [96]. According to Pinlova et al., (2024), NatureWorks, a leading company in the bioplastics industry produces PLA (Polylactic Acid), a biodegradable plastic made from agricultural feedstocks such as corn stover [27]. Their success stems from their advanced production techniques and strategic partnerships. The company collaborates with industry giants like Cargill and TotalEnergies to scale up production and ensure widespread distribution [97]. NatureWorks has implemented continuous improvements in its manufacturing process, reducing costs and enhancing the material properties of PLA. Their ability to secure large-scale contracts with major consumer goods and packaging companies has established PLA as a viable alternative to conventional plastics, driving its adoption in various applications from food packaging to disposable cutlery [98].

According to Roohi et al., (2023), Danimer Scientific, specializes in PHA (Polyhydroxyalkanoates), a bioplastic produced from food waste and other biomass sources [99].

Danimer's innovation lies in its use of waste biomass as a feedstock, which not only reduces production costs but also addresses the issue of waste management. The company has formed significant partnerships, including one with Mars Inc., to develop compostable packaging solutions [100].

This collaboration highlights how industry partnerships can facilitate the commercialization of bioplastics by integrating them into established supply chains and meeting the growing consumer demand for sustainable packaging options. Danimer's success in scaling its production capabilities and its ability to offer competitive pricing has helped establish PHA as a practical alternative to conventional plastics [101].

Similarly, according to Karishma et al., (2024), LanzaTech represents another innovative approach to bioplastics commercialization and has developed a process to convert industrial waste gases into ethanol, which can then be used as a feedstock for bioplastics production [102]. This method not only creates a valuable product from waste gases but also reduces reliance on traditional feedstocks like petroleum. The company's strategic partnerships with major corporations have facilitated the integration of their technology into industrial processes. By converting waste gases from steel mills and other industrial sources into ethanol, LanzaTech is pioneering a method that enhances the sustainability of bioplastic production while addressing industrial waste management issues [103].

C. Government Policies and Incentives regarding bioplastics

Government regulations, policies, and incentives play a crucial role in promoting the use of bioplastics derived from waste biomass. These measures are instrumental in shaping market dynamics and fostering industry growth by addressing the challenges of production costs, consumer acceptance, and environmental impact.

In the European Union, policies such as the Directive on Single-Use Plastics and the Circular Economy Action Plan have significantly influenced the bioplastics market [104]. The Single-Use Plastics Directive, enacted in 2019, aims to reduce plastic waste by banning certain single-use plastic items and encouraging the use of alternatives, including biodegradable bioplastics [105]. This regulation has driven demand for bioplastics by creating a market for sustainable packaging solutions. The Circular Economy Action Plan complements this by promoting a shift towards a circular economy, which includes funding for research and development in bioplastics technologies. The EU's commitment to sustainability and waste reduction has provided a robust regulatory framework that supports the growth of bioplastics from waste biomass, helping companies align with environmental goals and secure funding for innovation [106].

In the United States, state and federal policies also support the development and adoption of bioplastics. For instance, various states offer tax credits and subsidies to companies engaged in bioplastic production [107]. According to Awewomom et al., (2024), California, which is known for its stringent environmental regulations, provides incentives for the use of compostable materials through its green business programs [108]. These incentives help offset the higher production costs associated with bioplastics, making them more competitive with traditional plastics. Additionally, the Biodegradable Products Recovery Act at the federal level encourages the development and use of biodegradable plastics by offering grants and research funding [109]. This support helps companies lower production costs and improve the economic feasibility of bioplastics from waste biomass.s

China's approach to bioplastics is shaped by its Plastic Pollution Control Policy, which focuses on reducing plastic waste and promoting sustainable alternatives [15]. This policy has been instrumental in accelerating the adoption of bioplastics in various sectors, particularly packaging and agriculture [8]. China's emphasis on reducing plastic pollution has led to significant investments in bioplastics research and infrastructure, enabling the commercialization of bioplastics from waste biomass. The government's support extends to funding for innovative technologies and the development of recycling and composting facilities, which are crucial for the effective disposal and recycling of bioplastics [110].

According to Hereu-Morales et al., (2024), in Europe, the EU Green Deal has allocated significant funding to support sustainable practices, including bioplastics. This funding has facilitated the development of new technologies and the scaling of production capacities for bioplastics [111]. In the United States, California's incentive programs have enabled companies like BioLogiQ to expand their production of compostable bioplastics made from waste materials [112]. In China, the policy shift towards biodegradable plastics has supported companies like Green Dot Bioplastics in integrating bioplastics into the mainstream market [113].

VI. CHALLENGES IN BIOPLASTICS PRODUCTION FROM WASTE BIOMASS

Producing bioplastics from waste biomass offers numerous environmental benefits but also presents several challenges. These challenges span feedstock variability, scalability, technological barriers, and consumer acceptance [114]. Addressing these challenges is crucial for advancing bioplastics technology and achieving broader adoption.

A. Feedstock Variability

One of the major challenges in bioplastics production from waste biomass is the variability in feedstock composition and availability. Different sources of biomass, such as agricultural residues, food waste, or industrial by-products, have diverse compositions of cellulose, hemicellulose, and lignin, which affects the quality and yield of the resulting bioplastics.

For instance, corn stover, rice husk, and wheat straw each have different lignocellulosic structures, making it difficult to standardize bioplastics production processes [28]. This variability can result in inconsistent product performance, especially when scaling up to industrial levels. According to Synani et al., (2024), research from the University of Illinois has highlighted the need for pre-treatment standardization to manage the diverse composition of waste biomass [20].
Inconsistent feedstock quality can lead to inefficiencies in processing and variation in the material properties of the bioplastics. Furthermore, seasonal availability and logistical issues with sourcing waste biomass can make it difficult to ensure a continuous, reliable supply for large-scale production [28].

B. Scalability and Industrial Integration

Scaling up bioplastics production from lab-scale experiments to industrial processes presents significant technical and logistical challenges. One of the primary hurdles is integrating bioplastics production into existing industrial systems that were designed for conventional petrochemical plastics [115]. The capital expenditure required to retrofit existing plants or build new bioplastics facilities can be prohibitively high, especially for small and medium-sized enterprises [116]. The integration of bioplastics into industries like packaging and automotive requires not only high production volumes but also compatibility with existing machinery. This necessitates modifications in production processes to accommodate the different properties of bioplastics, such as their biodegradability and lower heat resistance compared to traditional plastics [117].

C. Technological Barriers

Several key technological barriers need to be addressed to make bioplastics from waste biomass more competitive with conventional plastics. Improving polymer properties such as mechanical strength, thermal stability, and durability remains a critical area of research [118]. Traditional bioplastic like PLA (polylactic acid) often struggle to match the strength and flexibility of petroleum-based plastics such as polypropylene and polyethylene [119].
Advancements in nanotechnology, such as the incorporation of nanocellulose or nanoclay into bioplastics, are being explored to improve these properties [71]. Additionally, improving production efficiency is essential to lower costs. Enzymatic hydrolysis and microbial fermentation processes, while effective, are still relatively expensive and energy-intensive compared to petrochemical methods. Innovations in catalyst design and bioprocessing could reduce the environmental footprint and cost of production.

D. Consumer Awareness and Acceptance

Despite the growing interest in sustainable products, consumer awareness and acceptance of bioplastics remain a challenge. Many consumers are still unaware of the benefits of bioplastics derived from waste biomass or hold misconceptions about their performance and environmental impact [120]. The term "biodegradable" can be misleading, as some bioplastics only degrade under specific industrial composting conditions, leading to confusion about their environmental benefits.
Educational campaigns are essential for increasing consumer awareness. For instance, Green Dot Bioplastics has launched marketing initiatives aimed at educating consumers about the performance and sustainability of their products [121]. However, more efforts are needed to overcome consumer skepticism, particularly regarding the price premium associated with bioplastics. Many consumers still perceive bioplastics as inferior in terms of durability or too costly compared to conventional plastics, which can slow down their adoption in everyday products. A recent 2024 survey conducted by Fletcher et al., indicated that while consumers are increasingly aware of plastic pollution, only about 30% understood the benefits of bioplastics, showing a significant gap in awareness and acceptance [122].

VII. FUTURE PROSPECTS FOR BIOPLASTICS FROM WASTE BIOMASS

The future of bioplastics from waste biomass is promising, driven by advancements in technology, evolving market dynamics, and the increasing emphasis on sustainability. Several key areas hold potential for shaping the future of this field, including emerging technologies, circular economy integration, and long-term sustainability.

A. Emerging Technologies

The future of bioplastics production from waste biomass will be shaped by several emerging technologies and innovations. One promising area is synthetic biology, which offers the potential to engineer microbes and enzymes to more efficiently convert waste biomass into monomers for bioplastics [123]. For example, microbes can be genetically modified to produce bioplastic precursors, such as lactic acid or PHA, directly from agricultural residues, food waste, or industrial by-products. These engineered organisms can be tailored to tolerate different feedstocks and optimize production yields [123].
Advanced material design is another critical frontier. According to Uysal-Unalam et al., (2024), scientists are working on designing bioplastics with enhanced properties, such as greater mechanical strength, improved barrier properties, and enhanced biodegradability [124]. Innovations like nanotechnology using nanocellulose, [71], and other nano-sized additives can improve the performance of bioplastics, making them competitive with traditional petroleum-based plastics. This opens up opportunities for applications in sectors like packaging, automotive, and electronics, where durability and performance are crucial.

Furthermore, AI-driven process optimization is becoming increasingly important. By leveraging machine learning and artificial intelligence, bioplastics producers can optimize the conversion processes of waste biomass, improving energy efficiency, reducing production costs, and minimizing environmental impacts [125]. AI can help predict the best conditions for enzymatic hydrolysis, fermentation, or polymerization, making the production process more efficient and scalable [125].

B. Circular Economy Integration

Bioplastics from waste biomass are inherently aligned with the principles of the circular economy, which seeks to maximize resource efficiency, minimize waste, and reduce environmental impact. By using waste biomass such as agricultural residues, food waste, and industrial by-products as raw materials, bioplastic production contributes to a more sustainable value chain [105]. These materials, which would otherwise be discarded or incinerated, are repurposed to create valuable products, reducing reliance on fossil fuels and lowering greenhouse gas emissions.

In a circular economy, the end-of-life management of bioplastics is also critical. Many bioplastics are biodegradable or compostable, meaning they can break down in natural environments or industrial composting facilities, closing the loop on resource use [93]. This reduces the accumulation of plastic waste in landfills and oceans, addressing the pressing issue of plastic pollution. Additionally, advancements in recycling technologies, such as chemical recycling, offer the potential to recover and reuse bioplastic materials, further enhancing the circularity of the production process [24].

The integration of bioplastics into a circular economy also promotes industrial symbiosis, where different industries collaborate to exchange waste streams and resources. For example, agricultural industries can supply residues to bioplastics producers, while the by-products of bioplastics production can be repurposed in other sectors, such as energy or fertilizers, creating a closed-loop system [125].

C. Long-term Sustainability

The long-term sustainability of bioplastics from waste biomass depends on several factors, including the availability of raw materials, environmental impacts, and alignment with global sustainability goals. Waste biomass offers a renewable and abundant feedstock, particularly in regions with significant agricultural, forestry, and food processing industries [20]. However, the scalability of bioplastics production will depend on maintaining a stable and consistent supply of high-quality biomass while ensuring that its use does not compete with food production or lead to deforestation [1].

In terms of environmental impact, bioplastics from waste biomass have the potential to significantly reduce carbon emissions and environmental degradation compared to conventional plastics. A life cycle assessment (LCA) of bioplastics shows that they generally have a lower carbon footprint and reduced reliance on non-renewable energy sources [75]. However, the overall sustainability of these materials will depend on factors such as energy use in production, land-use impacts, and the biodegradability or recyclability of the final products [75].

Bioplastics also align with global sustainability goals, such as the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) [126]. By promoting the use of renewable materials, reducing plastic waste, and lowering emissions, bioplastics contribute to global efforts to transition toward a more sustainable economy.

VIII. CONCLUSIONS

Bioplastics derived from waste biomass present a significant opportunity to address the growing environmental concerns related to conventional plastics. By utilizing agricultural residues, food waste, industrial by-products, municipal solid waste, and forest biomass residues, these bioplastics offer a sustainable alternative that can reduce dependency on fossil fuels, lower greenhouse gas emissions, and manage waste more effectively. Advancements in bioconversion technologies, including microbial fermentation and enzymatic hydrolysis, have streamlined the production of bioplastics, making the process more efficient and environmentally friendly. In particular, innovations like steam explosion, ionic liquids, and deep eutectic solvents have revolutionized feedstock pretreatment, while combined bioconversion techniques have maximized yield and minimized waste. The development of new polymerization methods, such as ring-opening polymerization for PLA and microbial PHA production, is improving the quality and material properties of bioplastics, making them competitive with traditional plastics.

However, despite the progress, the production of bioplastics from waste biomass faces several challenges. Feedstock variability, scalability, technological barriers, and consumer awareness remain key obstacles that must be addressed to achieve widespread industrial integration and market acceptance. Moreover, ensuring cost competitiveness against petroleum-based plastics continues to be a challenge, although utilizing waste biomass as feedstock offers a promising path to reducing production costs. The environmental impact of bioplastics, when assessed through Life Cycle Assessment (LCA), shows a marked reduction in carbon footprint and energy consumption compared to conventional plastics. Their biodegradability and compostability offer potential advantages in waste management, though existing infrastructure needs to be adapted for optimal integration. The role of government policies and incentives will be critical in promoting the adoption and growth of bioplastics, especially with regard to developing supportive regulations and fostering industry partnerships.

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Looking forward, the prospects for bioplastics from waste biomass are promising. Emerging technologies, such as synthetic biology and AI-driven optimization, will likely accelerate production efficiency and improve material properties. The integration of bioplastics into a circular economy, with a focus on resource efficiency and waste minimization, aligns well with global sustainability goals. In the long term, bioplastics from waste biomass have the potential to transform the plastics industry, offering an environmentally friendly and economically viable alternative that supports a more sustainable future.

By addressing current challenges and leveraging technological innovations, bioplastics from waste biomass can play a pivotal role in reducing the environmental impact of plastics, driving the industry towards a greener and more circular economy.

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REFERENCES

[1] B. Nisar, H. N. Pahalvi, A. Gulzar, S. Rashid, L. R. Majeed, and A. N. Kamili, “Chapter 25 - Bioplastics: solution to a green environment and sustainability,” in Role of Green Chemistry in Ecosystem Restoration to Achieve Environmental Sustainability, A. L. Srivastav, A. S. Grewal, Markandeya, and T. D. Pham, Eds., in Advances in Pollution Research. , Elsevier, 2024, pp. 261–269. doi: 10.1016/B978-0-443-15291-7.00021-3.
[2] S. K. Bhatia et al., “Biowaste-to-bioplastic (polyhydroxyalkanoates): Conversion technologies, strategies, challenges, and perspective,” Bioresour. Technol., vol. 326, p. 124733, 2021.
[3] G. Coppola, M. T. Gaudio, C. G. Lopresto, V. Calabro, S. Curcio, and S. Chakraborty, “Bioplastic from Renewable Biomass: A Facile Solution for a Greener Environment,” Earth Syst. Environ., vol. 5, no. 2, pp. 231–251, Jun. 2021, doi: 10.1007/s41748-021-00208-7.
[4] K. Rob, Data Lives: How Data Are Made and Shape Our World. Policy Press, 2021.
[5] B. E. Oßmann, “Microplastics in drinking water? Present state of knowledge and open questions,” Curr. Opin. Food Sci., vol. 41, pp. 44–51, Oct. 2021, doi: 10.1016/j.cofs.2021.02.011.
[6] J.-H. Kwon et al., “Microplastics in Food: A Review on Analytical Methods and Challenges,” Int. J. Environ. Res. Public. Health, vol. 17, no. 18, Art. no. 18, Jan. 2020, doi: 10.3390/ijerph17186710.
[7] S. V. L. Leonard et al., “Microplastics in human blood: Polymer types, concentrations and characterisation using μFTIR,” Environ. Int., vol. 188, p. 108751, Jun. 2024, doi: 10.1016/j.envint.2024.108751.
[8] X. Luan et al., “Dynamic material flow analysis of plastics in China from 1950 to 2050,” J. Clean. Prod., vol. 327, p. 129492, Dec. 2021, doi: 10.1016/j.jclepro.2021.129492.
[9] N. Harnkarnsujarit, P. Wongphan, T. Chatkitanan, Y. Laorenza, and A. Srisa, “Chapter 7 - Bioplastic for Sustainable Food Packaging,” in Sustainable Food Processing and Engineering Challenges, C. M. Galanakis, Ed., Academic Press, 2021, pp. 203–277. doi: 10.1016/B978-0-12-822714-5.00007-3.
[10] G. Atiwesh, A. Mikhael, C. C. Parrish, J. Banoub, and T.-A. T. Le, “Environmental impact of bioplastic use: A review,” Heliyon, vol. 7, no. 9, Sep. 2021, doi: 10.1016/j.heliyon.2021.e07918.
[11] A. Arif et al., “Bioplastics from waste biomass of marine and poultry industries,” J. Biosci., vol. 48, no. 2, p. 11, Mar. 2023, doi: 10.1007/s12038-023-00332-8.
[12] P. Choudhary, A. Pathak, P. Kumar, C. S, and N. Sharma, “Commercial production of bioplastic from organic waste–derived biopolymers viz-a-viz waste treatment: A minireview,” Biomass Convers. Biorefinery, vol. 14, no. 10, pp. 10817–10827, May 2024, doi: 10.1007/s13399-022-03145-1.
[13] B. Koul, M. Yakoob, and M. P. Shah, “Agricultural waste management strategies for environmental sustainability,” Environ. Res., vol. 206, p. 112285, Apr. 2022, doi: 10.1016/j.envres.2021.112285.
[14] F. and A. O. of the U. Nations, I. F. for A. Development, U. N. C. Fund, W. F. Program, and W. H. Organization, The State of Food Security and Nutrition in the World 2022: Repurposing food and agricultural policies to make healthy diets more affordable. Food & Agriculture Org., 2022.
[15] S. Ke, D. Qiao, X. Zhang, and Q. Feng, “Changes of China’s forestry and forest products industry over the past 40 years and challenges lying ahead,” For. Policy Econ., vol. 123, p. 102352, Feb. 2021, doi: 10.1016/j.forpol.2020.102352.
[16] A. Maalouf and A. Mavropoulos, “Re-assessing global municipal solid waste generation,” Waste Manag. Res., vol. 41, no. 4, pp. 936–947, Apr. 2023, doi: 10.1177/0734242X221074116.
[17] A. M. Shabbirahmed et al., “Sugarcane bagasse into value-added products: a review,” Environ. Sci. Pollut. Res., vol. 29, no. 42, pp. 62785–62806, Sep. 2022, doi: 10.1007/s11356-022-21889-1.
[18] D. C. McNeill et al., “Upcycling of ligno-cellulosic nutshells waste biomass in biodegradable plastic-based biocomposites uses - a comprehensive review,” Compos. Part C Open Access, vol. 14, p. 100478, Jul. 2024, doi: 10.1016/j.jcomc.2024.100478.
[19] Y. Ding et al., “All-Biomass-Derived Nanocomposite Films of Pullulan/Lactate-Nanocellulose/Hydrophobic Lignin for Eco-friendly and Practical Plastic Food-Packaging Alternatives,” ACS Sustain. Chem. Eng., vol. 12, no. 19, pp. 7443–7456, May 2024, doi: 10.1021/acssuschemeng.4c00816.
[20] K. Synani, K. Abeliotis, K. Velonia, A. Maragkaki, T. Manios, and K. Lasaridi, “Environmental Impact and Sustainability of Bioplastic Production from Food Waste,” Sustainability, vol. 16, no. 13, Art. no. 13, Jan. 2024, doi: 10.3390/su16135529.
[21] H. Venkatachalam and R. Palaniswamy, “Bioplastic world: A review,” J. Adv. Sci. Res., vol. 11, no. 03, pp. 43–53, 2020.
[22] R. Kumar et al., “An investigation of the environmental implications of bioplastics: Recent advancements on the development of environmentally friendly bioplastics solutions,” Environ. Res., vol. 244, p. 117707, Mar. 2024, doi: 10.1016/j.envres.2023.117707.
[23] K. J. Jem and B. Tan, “The development and challenges of poly (lactic acid) and poly (glycolic acid),” Adv. Ind. Eng. Polym. Res., vol. 3, no. 2, pp. 60–70, Apr. 2020, doi: 10.1016/j.aiepr.2020.01.002.
[24] M. Calisto Friant, W. J. V. Vermeulen, and R. Salomone, “Analysing European Union circular economy policies: words versus actions,” Sustain. Prod. Consum., vol. 27, pp. 337–353, Jul. 2021, doi: 10.1016/j.spc.2020.11.001.
[25] S. Vigneswari et al., “Turning agricultural waste streams into biodegradable plastic: A step forward into adopting sustainable carbon neutrality,” J. Environ. Chem. Eng., vol. 12, no. 2, p. 112135, Apr. 2024, doi: 10.1016/j.jece.2024.112135.
[26] S. P. Bangar and P. Kajla, Agro-Wastes for Packaging Applications. CRC Press, 2024.
[27] B. Pinlova, A. Sudheshwar, K. Vogel, N. Malinverno, R. Hischier, and C. Som, “What can we learn about the climate change impacts of polylactic acid from a review and meta-analysis of lifecycle assessment studies?,” Sustain. Prod. Consum., vol. 48, pp. 396–406, Jul. 2024, doi: 10.1016/j.spc.2024.05.021.
[28] J. Li, Y. Wang, C. Xu, S. Liu, J. Dai, and K. Lan, “Bioplastic derived from corn stover: Life cycle assessment and artificial intelligence-based analysis of uncertainty and variability,” Sci. Total Environ., vol. 946, p. 174349, Oct. 2024, doi: 10.1016/j.scitotenv.2024.174349.
[29] P. Brites, M. I. S. Aguiar, J. Gonçalves, P. Ferreira, and C. Nunes, “Sustainable valorisation of bioactive molecules from rice husks through hydrothermal extraction for chitosan-based bioplastic production,” Int. J. Biol. Macromol., vol. 271, p. 132489, Jun. 2024, doi: 10.1016/j.ijbiomac.2024.132489.

[30] R. S. K. Sachan et al., "Investigating chemical pre-treatment methods: Valorization of wheat straw to enhance polyhydroxyalkanoate (PHA) production with novel isolate Bacillus paranthracis RSKS-3," Heliyon, vol. 10, no. 11, Jun. 2024, doi: 10.1016/j.heliyon.2024.e31572.
[31] R. Patidar et al., "Production of Natural Straw-Derived Sustainable Polymer Composites for a Circular Agro-Economy," ACS Sustain. Resour. Manag., vol. 1, no. 8, pp. 1729–1737, Aug. 2024, doi: 10.1021/acssusresmgt.4c00054.
[32] D. Kadam, P. Arte, A. De, K. Tungare, M. Bhori, and A. Kadam, "Chapter 6 - Phytochemicals from fruit wastes," in Adding Value to Fruit Wastes, S. P. Bangar and P. S. Panesar, Eds., Academic Press, 2024, pp. 167–188. doi: 10.1016/B978-0-443-13842-3.00006-X.
[33] [33] S. Mihalyi et al., "The orange gold: Biotechnological production of PLA/P(3HB)/limonene based polyesters from orange peel waste," Sustain. Mater. Technol., vol. 41, p. e01110, Sep. 2024, doi: 10.1016/j.susmat.2024.e01110.
[34] T. H. Taha et al., "Profitable exploitation of biodegradable polymer including chitosan blended potato peels' starch waste as an alternative source of petroleum plastics," Biomass Convers. Biorefinery, vol. 14, no. 1, pp. 207–215, Jan. 2024, doi: 10.1007/s13399-021-02244-9.
[35] A. Arooj, M. Khan, and K. S. Munawar, "Preparation and physicochemical characterization of starch/pectin and chitosan blend bioplastic films as future food packaging materials," J. Environ. Chem. Eng., vol. 12, no. 1, p. 111825, Feb. 2024, doi: 10.1016/j.jece.2023.111825.
[36] G. Ali, M. Sharma, E.-S. Salama, Z. Ling, and X. Li, "Applications of chitin and chitosan as natural biopolymer: potential sources, pretreatments, and degradation pathways," Biomass Convers. Biorefinery, vol. 14, no. 4, pp. 4567–4581, Feb. 2024, doi: 10.1007/s13399-022-02684-x.
[37] J. Panda, A. K. Mishra, Y. K. Mohanta, K. Patowary, P. R. Rauta, and B. Mishra, "Exploring Biopolymer for Food and Pharmaceuticals Application in the Circular Bioeconomy: An Agro-Food Waste-to-Wealth Approach," Waste Biomass Valorization, Mar. 2024, doi: 10.1007/s12649-024-02452-0.
[38] X. Xu, B. Wang, W. Gao, J. Sui, J. Wang, and B. Cui, "Effect of different proportions of glycerol and D-mannitol as plasticizer on the properties of extruded corn starch," Front. Nutr., vol. 10, Jan. 2024, doi: 10.3389/fnut.2023.1335812.
[39] H. Chung, "Lignin based biodegradable polymers and methods of making the same," WO2021142079A1, Jul. 15, 2021 Accessed: Sep. 11, 2024. [Online]. Available: https://patents.google.com/patent/WO2021142079A1/en
[40] P. Tomani, "The LignoCity initiative," presented at the 7th Nordic Wood Biorefinery Conference held in Stockholm, Sweden, 28-30 Mar. 2017, RISE Bioekonomi, 2017, pp. 76–81. Accessed: Sep. 11, 2024. [Online]. Available: https://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-29754
[41] G.-J. M. Gruter and T. B. van Aken, "14. Making an Impact: Sustainable Success Stories: Avantium," in How to Commercialize Chemical Technologies for a Sustainable Future, John Wiley & Sons, Ltd, 2021, pp. 263–270. doi: 10.1002/9781119604860.ch14b.
[42] I. Alawad and H. Ibrahim, "Pretreatment of agricultural lignocellulosic biomass for fermentable sugar: opportunities, challenges, and future trends," Biomass Convers. Biorefinery, vol. 14, no. 5, pp. 6155–6183, Mar. 2024, doi: 10.1007/s13399-022-02981-5.
[43] J.-R. Ventura and R. L. Ventura, "Techno-Economic Feasibility of Polyhydroxybutyrate (PHB) Production from Corn Stover," Philipp. Agric. Sci., vol. 107, no. 1, Mar. 2024, [Online]. Available: https://www.ukdr.uplb.edu.ph/pas/vol107/iss1/3
[44] M. Hassegawa, A. Karlberg, M. Hertzberg, and P. J. Verkerk, "Innovative forest products in the circular bioeconomy," Open Res. Eur., vol. 2, p. 19, Jun. 2022, doi: 10.12688/openreseurope.14413.2.
[45] M. Mariana et al., "A current advancement on the role of lignin as sustainable reinforcement material in biopolymeric blends," J. Mater. Res. Technol., vol. 15, pp. 2287–2316, Nov. 2021, doi: 10.1016/j.jmrt.2021.08.139.
[46] M. M. Abe, M. C. Branciforti, and M. Brienzo, "Biodegradation of Hemicellulose-Cellulose-Starch-Based Bioplastics and Microbial Polyesters," Recycling, vol. 6, no. 1, Art. no. 1, Mar. 2021, doi: 10.3390/recycling6010022.
[47] M. Ismayati et al., "Antioxidant and UV-blocking activity of PVA/tannin-based bioplastics in food packaging application," Int. J. Biol. Macromol., vol. 257, p. 128332, Feb. 2024, doi: 10.1016/j.ijbiomac.2023.128332.
[48] T. R. Sarker, F. Pattnaik, S. Nanda, A. K. Dalai, V. Meda, and S. Naik, "Hydrothermal pretreatment technologies for lignocellulosic biomass: A review of steam explosion and subcritical water hydrolysis," Chemosphere, vol. 284, p. 131372, Dec. 2021, doi: 10.1016/j.chemosphere.2021.131372.
[49] P. Y. S. Nakasu, P. V. Barbará, A. E. J. Firth, and J. P. Hallett, "Pretreatment of biomass with protic ionic liquids," Trends Chem., vol. 4, no. 3, pp. 175–178, Mar. 2022, doi: 10.1016/j.trechm.2021.12.001.
[50] V. Sharma et al., "Deep eutectic solvents as promising pretreatment agents for sustainable lignocellulosic biorefineries: A review," Bioresour. Technol., vol. 360, p. 127631, Sep. 2022, doi: 10.1016/j.biortech.2022.127631.
[51] S. Varghese et al., "Leads and hurdles to sustainable microbial bioplastic production," Chemosphere, vol. 305, p. 135390, Oct. 2022, doi: 10.1016/j.chemosphere.2022.135390.
[52] M. W. Myburgh, W. H. van Zyl, M. Modesti, M. Viljoen-Bloom, and L. Favaro, "Enzymatic hydrolysis of single-use bioplastic items by improved recombinant yeast strains," Bioresour. Technol., vol. 390, p. 129908, Dec. 2023, doi: 10.1016/j.biortech.2023.129908.
[53] A. Ahmad, F. Banat, H. Alsafar, and S. W. Hasan, "An overview of biodegradable poly (lactic acid) production from fermentative lactic acid for biomedical and bioplastic applications," Biomass Convers. Biorefinery, vol. 14, no. 3, pp. 3057–3076, Feb. 2024, doi: 10.1007/s13399-022-02581-3.
[54] F. M. de Souza and R. K. Gupta, "Bacteria for Bioplastics: Progress, Applications, and Challenges," ACS Omega, vol. 9, no. 8, pp. 8666–8686, Feb. 2024, doi: 10.1021/acsomega.3c07372.
[55] T. Rasheed et al., "Recent updates on biodegradability and recyclability of bioplastics - Towards a new era in sustainability," Sustain. Mater. Technol., vol. 41, p. e01051, Sep. 2024, doi: 10.1016/j.susmat.2024.e01051.
[56] L. Gong et al., "Sustainable utilization of fruit and vegetable waste bioresources for bioplastics production," Crit. Rev. Biotechnol., vol. 44, no. 2, pp. 236–254, Feb. 2024, doi: 10.1080/07388551.2022.2157241.
[57] J. Yang et al., "Effects of silane hydrolysis time on the physicochemical properties of bioplastics based on starch and epoxidized soybean oil," Food Chem., vol. 460, p. 140601, Dec. 2024, doi: 10.1016/j.foodchem.2024.140601.
[58] N. Jaiswal and P. Jaiswal, "Thermostable α-Amylases and Laccases: Paving the Way for Sustainable Industrial Applications," Processes, vol. 12, no. 7, Art. no. 7, Jul. 2024, doi: 10.3390/pr12071341.
[59] M. Singh and U. Dutta, "Biodegradation of Kitchen Waste mediated by Fungal Enzyme cocktail," Jan. 01, 2024. doi: 10.21203/rs.3.rs-3804538/v1.
[60] D. Cai et al., "Alkali Pretreated Corn Stalk Combined with Enzyme Cocktail at Low Cellulase Dosage for the High-Titer L-Lactic Acid Production," Apr. 16, 2024, Rochester, NY: 4796301. doi: 10.2139/ssrn.4796301.
[61] S. Srivastava and N. A. Dafale, "Tailored microbial consortium producing hydrolytic enzyme cocktail for maximum saccharification of wheat straw," Bioresour. Technol., vol. 399, p. 130560, May 2024, doi: 10.1016/j.biortech.2024.130560.
[62] R. Hernández Pérez, R. Salgado Delgado, A. Olarte Paredes, A. M. Salgado Delgado, B. Flores Abarca, and O. E. Silva Astudillo, "Combined Hydrolysis to Yield Increase of Cellulose and (CNCs), Starting from Agroindustrial Rice Husk Waste in Morelos, Mexico," J. Water Environ. Nanotechnol., vol. 9, no. 2, pp. 124–136, May 2024, doi: 10.22090/jwent.2024.02.01.
[63] Y. Cao, M. Xu, J. Lu, and G. Cai, "Simultaneous Microbial Fermentation and Enzymolysis: A Biotechnology Strategy to Improve the Nutritional and Functional Quality of Soybean Meal," Food Rev. Int., vol. 40, no. 5, pp. 1296–1311, Jul. 2024, doi: 10.1080/87559129.2023.2212048.
[64] S. Mondal, S. Neogi, and S. Chakraborty, "Optimization of reactor parameters for amplifying synergy in enzymatic co-hydrolysis and microbial co-fermentation of lignocellulosic agro-residues," Renew. Energy, vol. 225, p. 120281, May 2024, doi: 10.1016/j.renene.2024.120281.

[65] A. Reza Monfared et al., "Empowering PLA Bioplastics: Elevating applications horizon through groundbreaking Eco-Innovative Fibrillation, chain Extension, and crosslinking techniques," Chem. Eng. J., vol. 496, p. 154181, Sep. 2024, doi: 10.1016/j.cej.2024.154181.
[66] P. Thamarai, A. S. Vickram, A. Saravanan, V. C. Deivayanai, and S. Evangeline, "Recent advancements in biosynthesis, industrial production, and environmental applications of polyhydroxyalkanoates (PHAs): A review," Bioresour. Technol. Rep., vol. 27, p. 101957, Sep. 2024, doi: 10.1016/j.biteb.2024.101957.
[67] E. K. B. Roman et al., "Plastic-degrading microbial communities reveal novel microorganisms, pathways, and biocatalysts for polymer degradation and bioplastic production," Sci. Total Environ., vol. 949, p. 174876, Nov. 2024, doi: 10.1016/j.scitotenv.2024.174876.
[68] B. Kommula et al., "Waste Polyethylene-Derived Carbon Dots: Administration of Metal-Free Oxidizing Agents for Tunable Properties and Photocatalytic Hyperactivity," ACS Appl. Mater. Interfaces, vol. 16, no. 30, pp. 39470–39481, Jul. 2024, doi: 10.1021/acsami.4c08635.
[69] S. A. Siddiqui, X. Yang, R. K. Deshmukh, K. K. Gaikwad, N. A. Bahmid, and R. Castro-Muñoz, "Recent advances in reinforced bioplastics for food packaging – A critical review," Int. J. Biol. Macromol., vol. 263, p. 130399, Apr. 2024, doi: 10.1016/j.ijbiomac.2024.130399.
[70] Nguyen Chi Thanh, N. B. A. Duy, H. T. H. Xuyen, N. T. Huy, B. P. Dong, and T. Q. Giang, "Environmentally Friendly Bioplastic Films Based on Avocado Seeds Starch and Nanocellulose Fibers," Polym. Sci. Ser. A, Jul. 2024, doi: 10.1134/S0965545X23600485.
[71] A. M. Tatagar, J. I. Moodi, G. L. Vanti, and B. Murgunde, "Development of sustainable ternary bionanocomposite film reinforced with nanocellulose and nanoclay for microbial efficacy," J. Mater. Sci., vol. 59, no. 15, pp. 6334–6353, Apr. 2024, doi: 10.1007/s10853-024-09568-7.
[72] Z. Huang, Y. Zhang, C. Zhang, F. Yuan, H. Gao, and Q. Li, "Lignin-Based Composite Film and Its Application for Agricultural Mulching," Polymers, vol. 16, no. 17, Art. no. 17, Jan. 2024, doi: 10.3390/polym16172488.
[73] D. Friedrich, Applied Building Physics and Materials Science of Natural Fiber Reinforced Plastics: A Guide for Study and Practice. Wiesbaden: Springer Fachmedien, 2024. doi: 10.1007/978-3-658-41132-9.
[74] M. Islam, T. Xayachak, N. Haque, D. Lau, M. Bhuiyan, and B. K. Pramanik, "Impact of bioplastics on environment from its production to end-of-life," Process Saf. Environ. Prot., vol. 188, pp. 151–166, Aug. 2024, doi: 10.1016/j.psep.2024.05.113.
[75] A. L. Tecorralco-Bobadilla, A. Vázquez-Morillas, G. González-Cardoso, and P. X. Sotelo-Navarro, "Life Cycle Assessment (LCA) of Bioplastics," in Toxic Effects of Micro- and Nanoplastics, John Wiley & Sons, Ltd, 2024, pp. 21–59. doi: 10.1002/9781394238163.ch2.
[76] S. S. Ali et al., "Bioplastic production in terms of life cycle assessment: A state-of-the-art review," Environ. Sci. Ecotechnology, vol. 15, p. 100254, Jul. 2023, doi: 10.1016/j.ese.2023.100254.
[77] M. I. R. Morris and A. L. Hicks, "A human-centered review of life cycle assessments of bioplastics," Int. J. Life Cycle Assess., vol. 27, no. 1, pp. 157–172, Jan. 2022, doi: 10.1007/s11367-021-02001-0.
[78] Z. Qi et al., "Comparison of Properties of Poly(Lactic Acid) Composites Prepared from Different Components of Corn Straw Fiber," Int. J. Mol. Sci., vol. 23, no. 12, Art. no. 12, Jan. 2022, doi: 10.3390/ijms23126746.
[79] A. Folino, D. Pangallo, and P. S. Calabrò, "Assessing bioplastics biodegradability by standard and research methods: Current trends and open issues," J. Environ. Chem. Eng., vol. 11, no. 2, p. 109424, Apr. 2023, doi: 10.1016/j.jece.2023.109424.
[80] S. Nizamuddin, A. J. Baloch, C. Chen, M. Arif, and N. M. Mubarak, "Bio-based plastics, biodegradable plastics, and compostable plastics: biodegradation mechanism, biodegradability standards and environmental stratagem," Int. Biodeterior. Biodegrad., vol. 195, p. 105887, Nov. 2024, doi: 10.1016/j.ibiod.2024.105887.
[81] M. Lackner, A. Mukherjee, and M. Koller, "What Are 'Bioplastics'? Defining Renewability, Biosynthesis, Biodegradability, and Biocompatibility," Polymers, vol. 15, no. 24, Art. no. 24, Jan. 2023, doi: 10.3390/polym15244695.
[82] W. A. Ahsan, A. Hussain, C. Lin, and M. K. Nguyen, "Biodegradation of Different Types of Bioplastics through Composting—A Recent Trend in Green Recycling," Catalysts, vol. 13, no. 2, Art. no. 2, Feb. 2023, doi: 10.3390/catal13020294.
[83] V. Goel, P. Luthra, G. S. Kapur, and S. S. V. Ramakumar, "Biodegradable/Bio-plastics: Myths and Realities," J. Polym. Environ., vol. 29, no. 10, pp. 3079–3104, Oct. 2021, doi: 10.1007/s10924-021-02099-1.
[84] M. Fogašová et al., "PLA/PHB-Based Materials Fully Biodegradable under Both Industrial and Home-Composting Conditions," Polymers, vol. 14, no. 19, Art. no. 19, Jan. 2022, doi: 10.3390/polym14194113.
[85] G. Vinci, R. Ruggieri, A. Billi, C. Pagnozzi, M. V. Di Loreto, and M. Ruggeri, "Sustainable Management of Organic Waste and Recycling for Bioplastics: A LCA Approach for the Italian Case Study," Sustainability, vol. 13, no. 11, Art. no. 11, Jan. 2021, doi: 10.3390/su13116385.
[86] E. C. Van Roijen and S. A. Miller, "A review of bioplastics at end-of-life: Linking experimental biodegradation studies and life cycle impact assessments," Resour. Conserv. Recycl., vol. 181, p. 106236, Jun. 2022, doi: 10.1016/j.resconrec.2022.106236.
[87] A. Abraham, H. Park, O. Choi, and B.-I. Sang, "Anaerobic co-digestion of bioplastics as a sustainable mode of waste management with improved energy production – A review," Bioresour. Technol., vol. 322, p. 124537, Feb. 2021, doi: 10.1016/j.biortech.2020.124537.
[88] S. V. Afshar, A. Boldrin, T. F. Astrup, A. E. Daugaard, and N. B. Hartmann, "Degradation of biodegradable plastics in waste management systems and the open environment: A critical review," J. Clean. Prod., vol. 434, p. 140000, Jan. 2024, doi: 10.1016/j.jclepro.2023.140000.
[89] T. Cooke and R. S. Pomeroy, "Chapter 11 - The bioplastics market: History, commercialization trends, and the new eco-consumer," in Rethinking Polyester Polyurethanes, R. S. Pomeroy, Ed., in Emerging Issues in Analytical Chemistry. , Elsevier, 2023, pp. 261–280. doi: 10.1016/B978-0-323-99982-3.00003-1.
[90] A. Arun, K. Zhang, S. Muniyasamy, and R. Raja, Biodegradable Polymers, Blends and Biocomposites: Trends and Applications. CRC Press, 2024.
[91] N. M. Döhler and A. Wolf, "Business Models for Innovative Bioplastic Feedstocks," in Second and Third Generation Bioplastics, CRC Press, 2023.
[92] E. Waltz, "Microbe-made jet fuel," Nat. Biotechnol., vol. 42, no. 2, pp. 163–166, Feb. 2024, doi: 10.1038/s41587-024-02136-z.
[93] N. Parveen, S. V. C. S. Naik, K. R. Vanapalli, and H. B. Sharma, "Bioplastic packaging in circular economy: A systems-based policy approach for multi-sectoral challenges," Sci. Total Environ., vol. 945, p. 173893, Oct. 2024, doi: 10.1016/j.scitotenv.2024.173893.
[94] S. V. Suba, P. Sangavi, K. Nachammai, and K. Langeswaran, "Economics of Bioplastics and Biobased Products," in Biodegradable Polymers, Blends and Biocomposites, CRC Press, 2024.
[95] H. Park, H. He, X. Yan, X. Liu, N. S. Scrutton, and G.-Q. Chen, "PHA is not just a bioplastic!," Biotechnol. Adv., vol. 71, p. 108320, Mar. 2024, doi: 10.1016/j.biotechadv.2024.108320.
[96] P. Torres Lepe, K. V. Heredia, E. Cárdenas Namur, G. C. Sandoval Fabián, and S. García-Enriquez, "12 - Economics and commercialization of bioplastics," in Bioplastics for Sustainability, A. K. Mishra and C. M. Hussain, Eds., Elsevier, 2024, pp. 271–309. doi: 10.1016/B978-0-323-95199-9.00018-4.
[97] W. H. Money and K. E. Money, "A review of natural resource extraction industries and their influence on the occurrence of poverty," J. Strategy Manag., vol. ahead-of-print, no. ahead-of-print, Jan. 2024, doi: 10.1108/JSMA-07-2023-0183.
[98] A. Pisupati, M. Leroy, T. Laurent, and C. H. Park, "Development and investigation of nonwoven preforms for self-reinforced polylactic acid composites," J. Reinf. Plast. Compos., vol. 43, no. 1–2, pp. 72–83, Jan. 2024, doi: 10.1177/07316844231155805.
[99] Roohi, N. Bano, A. Gupta, M. H. Siddiqui, and M. R. Zaheer, "Potential of PHA (Polyhydroxyalkanoates) Polymers as Packaging Materials: From Concept to Commercialization," in Biobased Packaging Materials: Sustainable Alternative to Conventional Packaging Materials, S. Ahmed, Ed., Singapore: Springer Nature, 2023, pp. 67–100. doi: 10.1007/978-981-99-6050-7_3.

[100] K. W. Dotson, K. Pisano, and D. A. Renegar, "Surface Erosion Equations for Degradation Analysis of Several Common Three-Dimensional Shapes of Plastic Materials," J. Polym. Environ., Jun. 2024, doi: 10.1007/s10924-024-03291-9.
[101] J. C. C. Yeo et al., "Innovative biomaterials for food packaging: Unlocking the potential of polyhydroxyalkanoate (PHA) biopolymers," Biomater. Adv., vol. 163, p. 213929, Oct. 2024, doi: 10.1016/j.bioadv.2024.213929.
[102] S. Karishma, R. Kamalesh, A. Saravanan, V. C. Deivayanai, P. R. Yaashikaa, and A. S. Vickram, "A review on recent advancements in biochemical fixation and transformation of CO2 into constructive products," Biochem. Eng. J., vol. 208, p. 109366, Aug. 2024, doi: 10.1016/j.bej.2024.109366.
[103] N. B. Devi, G. Pugazhenthi, and K. Pakshirajan, "Synthetic biology approaches and bioseparations in syngas fermentation," Trends Biotechnol., vol. 0, no. 0, Aug. 2024, doi: 10.1016/j.tibtech.2024.07.008.
[104] [V. Ross, L. de Almeida, J. van Leeuwen, and J. van Zeben, "Reflexive EU environmental law: Exploring divergence in the French and German transposition of the Single-use Plastics Directive," Rev. Eur. Comp. Int. Environ. Law, Jul. 2024, doi: 10.1111/reel.12564.
[105] M. Boeve and I. M. de Waal, "Global Plastic Pollution and the Transition Towards a Circular Economy: Lessons from the EU's Legal Framework on Plastics," Environ. Policy Law, vol. 53, no. 5–6, pp. 461–472, Jan. 2023, doi: 10.3233/EPL-239016.
[106] S. Eckert, O. Karassin, and Y. Steinebach, "A policy portfolio approach to plastics throughout their life cycle: Supranational and national regulation in the European Union," Environ. Policy Gov., vol. 34, no. 4, pp. 427–441, 2024, doi: 10.1002/eet.2092.
[107] M. Aydin, T. Degirmenci, O. Bozatli, and D. Balsalobre-Lorente, "Fresh evidence of the impact of economic complexity, health expenditure, natural resources, plastic consumption, and renewable energy in air pollution deaths in the USA? An empirical approach," Sci. Total Environ., vol. 921, p. 171127, 2024.
[108] J. Awewomom et al., "Addressing global environmental pollution using environmental control techniques: a focus on environmental policy and preventive environmental management," Discov. Environ., vol. 2, no. 1, p. 8, Feb. 2024, doi: 10.1007/s44274-024-00033-5.
[109] J. A. Aitken et al., "Initial assessment of the efficacy of food recovery policies in US States for increasing food donations and reducing waste," Waste Manag., vol. 176, pp. 149–158, Mar. 2024, doi: 10.1016/j.wasman.2023.12.051.
[110] S. Ren et al., "Potential sources and occurrence of macro-plastics and microplastics pollution in farmland soils: A typical case of China," Crit. Rev. Environ. Sci. Technol., vol. 54, no. 7, pp. 533–556, Apr. 2024, doi: 10.1080/10643389.2023.2259275.
[111] J. Hereu-Morales, A. Segarra, and C. Valderrama, "The European (Green?) Deal: a systematic analysis of environmental sustainability," Sustain. Dev., vol. 32, no. 1, pp. 647–661, 2024, doi: 10.1002/sd.2671.
[112] M. T. Khan et al., "Microplastic Pollution in Aquatic Ecosystem: A Review of Existing Policies and Regulations," Chemosphere, p. 143221, 2024.
[113] A. Hao, T. Dogot, and C. Yin, "How to enhance agricultural plastic waste management in China? Insights from public participation," J. Integr. Agric., vol. 23, no. 6, pp. 2127–2143, 2024.
[114] S. Gautam, A. Gautam, J. Pawaday, R. K. Kanzariya, and Z. Yao, "Current Status and Challenges in the Commercial Production of Polyhydroxyalkanoate-Based Bioplastic: A Review," Processes, vol. 12, no. 8, Art. no. 8, Aug. 2024, doi: 10.3390/pr12081720.
[115] Y. Yang, K. Seo, J. S.-I. Kwon, and W. Won, "Process Integration for the Production of Bioplastic Monomer: Techno-Economic Analysis and Life-Cycle Assessment," ACS Sustain. Chem. Eng., vol. 12, no. 30, pp. 11167–11180, Jul. 2024, doi: 10.1021/acssuschemeng.4c01783.
[116] T. Börner and M. Zinn, "Key challenges in the advancement and industrialization of biobased and biodegradable plastics: a value chain overarching perspective," Front. Bioeng. Biotechnol., vol. 12, Jul. 2024, doi: 10.3389/fbioe.2024.1406278.
[117] M. Ayala et al., "A supply-chain perspective on producing and upscaling bioplastic from cultivated brown seaweed," J. Clean. Prod., vol. 444, p. 141248, Mar. 2024, doi: 10.1016/j.jclepro.2024.141248.
[118] D. D. Kapoor, S. Yadav, and R. Kr. Gupta, "Comprehensive study of microbial bioplastic: present status and future perspectives for sustainable development," Environ. Dev. Sustain., vol. 26, no. 9, pp. 21985–22011, Sep. 2024, doi: 10.1007/s10668-023-03620-3.
[119] M. Degli Esposti et al., "The role of biotechnology in the transition from plastics to bioplastics: an opportunity to reconnect global growth with sustainability," FEBS Open Bio, vol. 11, no. 4, pp. 967–983, Apr. 2021, doi: 10.1002/2211-5463.13119.
[120] M. L. Baskoro, B. Tjahjono, M. Beltran, A. Bogush, and R. K. Brahmana, "Exploring the efficacy of ecolabels as a marketing strategy: Insights from the emerging bioplastic packaging market," Bus. Strategy Environ., vol. n/a, no. n/a, doi: 10.1002/bse.3891.
[121] A. Skouloudis, C. Malesios, and D.-F. Lekkas, "Notes from the Field: Public Views on Bioplastics-Findings from Greece," Circ. Econ. Sustain., vol. 4, no. 1, pp. 791–813, Mar. 2024, doi: 10.1007/s43615-023-00307-9.
[122] C. A. Fletcher et al., "Implications of consumer orientation towards environmental sustainability on the uptake of bio-based and biodegradable plastics," Curr. Res. Environ. Sustain., vol. 7, p. 100246, Jan. 2024, doi: 10.1016/j.crsust.2024.100246.
[123] M. Mandal, A. Roy, D. Mitra, and A. Sarkar, "Possibilities and Prospects of Bioplastics Production from Agri-waste using Bacterial Communities: Finding a Silver-Lining in Waste Management," Curr. Res. Microb. Sci., p. 100274, 2024.
[124] I. Uysal-Unalan et al., "Bioplastic packaging for fresh meat and fish: Current status and future direction on mitigating food and packaging waste," Trends Food Sci. Technol., p. 104660, 2024.
[125] M. Ghasemlou, C. J. Barrow, and B. Adhikari, "The future of bioplastics in food packaging: An industrial perspective," Food Packag. Shelf Life, vol. 43, p. 101279, 2024.
[126] Z. Islam Rony, M. G. Rasul, M. I. Jahirul, and M. Mofijur, "Harnessing marine biomass for sustainable fuel production through pyrolysis to support United Nations' Sustainable Development Goals," Fuel, vol. 358, p. 130099, Feb. 2024, doi: 10.1016/j.fuel.2023.130099.

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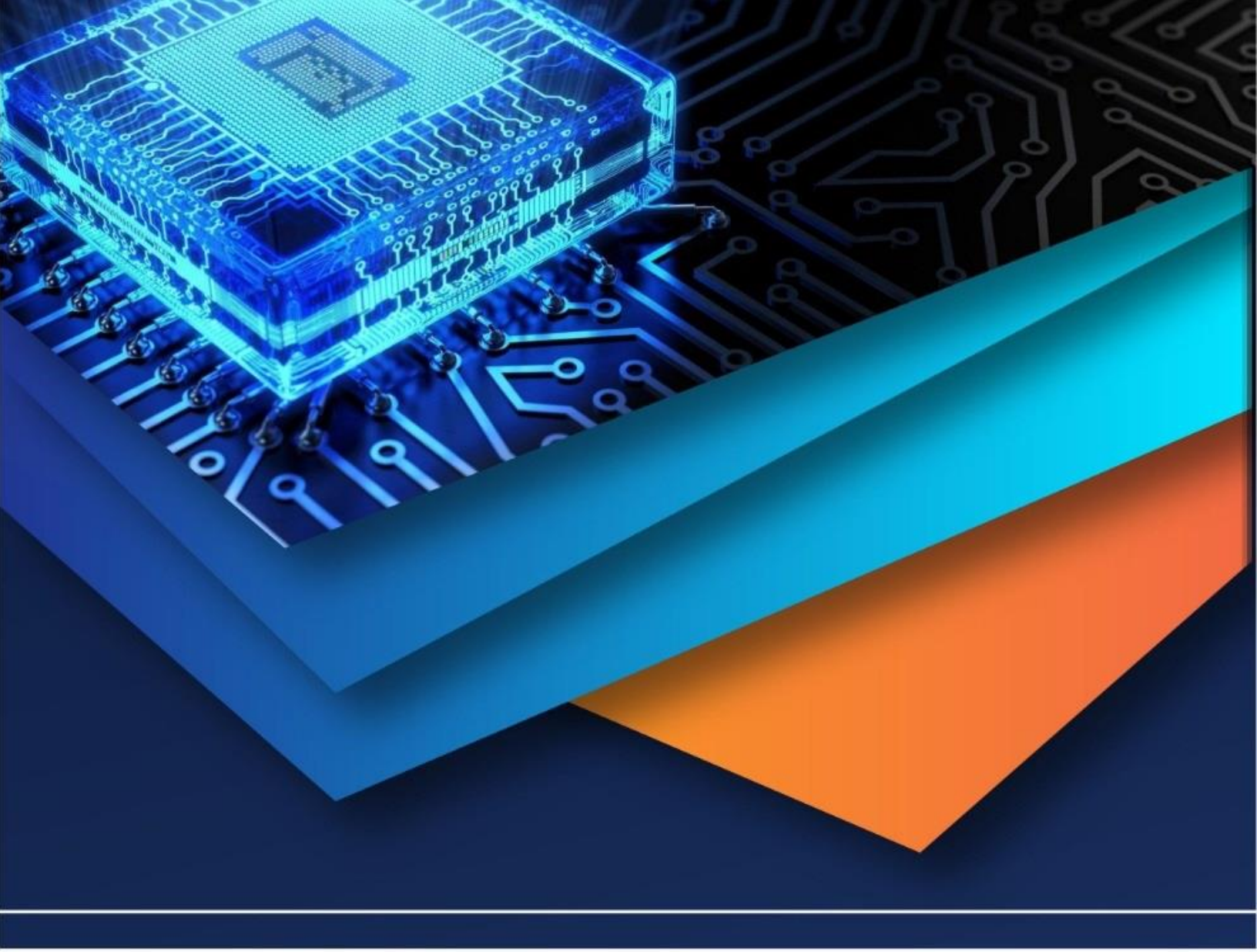

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