sustainability

MDPI

Review

Technology Analysis and Research Directions for Sustainable Bioresource-Based Material Alternatives: A Patent- and Literature-Based Analysis

Jeong Yeon Choi [1,*] and Hee Kyung An [2]

[1] Biomedical Manufacturing Technology Center, Mobility and Robot Systems Group, Korea Institute of Industrial Technology (KITECH), 320 Technosunhwan-ro, Yuga-eup, Dalseong-gun, Daegu 42994, Republic of Korea
[2] Mobility and Robot Systems Group, Korea Institute of Industrial Technology (KITECH), 320 Technosunhwan-ro, Yuga-eup, Dalseong-gun, Daegu 42994, Republic of Korea; ruth@kitech.re.kr
* Correspondence: jychoi77@kitech.re.kr

Abstract

This study analyzes selected international patent documents and the scientific literature to identify major Technology Elements and evidence-based research directions for sustainable bioresource-based material alternatives. Patent documents publicly available during the most recent 10-year period were searched, and documents representing the same invention or continuous rights were consolidated into 34 Patent Families. Technical evidence from abstracts and claims was organized according to six Technology Elements: bioresource, pretreatment, materialization, functionalization, application, and end-of-life (EOL). Eighteen scientific literature sources were considered, with recent studies prioritized for current research needs and relevant methodological and foundational studies included where necessary to establish the analytical framework. Agricultural by-products, food and organic wastes, spent coffee grounds, fruit residues, and algal biomass were repeatedly identified as major bioresource categories. Pretreatment and materialization technologies were broadly represented, whereas direct links among EOL and integrated environmental and safety assessment were relatively limited. These findings indicate that future research should strengthen connections among feedstock characterization, low-burden pretreatment, high-value materialization, functional performance, environmental and safety assessment, and EOL pathways. Research directions were derived by cross-checking technical approaches disclosed in patent titles, abstracts, claims, and relevant bibliographic information with research needs reported in the scientific literature rather than by applying an arbitrary scoring or technology-opportunity ranking system. This evidence-based Technology Network perspective provides a transparent basis for identifying research considerations for sustainable bioresource-based material alternatives.

Keywords: bioresource; agricultural waste; bioplastics; circular bioeconomy; biorefinery; end-of-life; life cycle assessment; sustainable materials; patent analysis

Check for updates

Academic Editors: Farshid Pahlevani and Smitirupa Biswal

Received: 14 September 2026
Revised: 7 October 2026
Accepted: 20 October 2026
Published: 24 October 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

The transition toward a circular and sustainable materials economy has accelerated research on the utilization of biomass and organic waste as alternative feedstocks for material production. Agricultural residues, food-processing by-products, and other bioresources

are increasingly investigated as sources of polymers, fibers, composites, functional components, and carbon-based materials. Such approaches can contribute to resource efficiency by redirecting underutilized biomass into higher-value products and by reducing dependence on conventional fossil-derived feedstocks [1,2]. However, the designation of a material as bio-based or biomass-derived does not, by itself, establish its overall sustainability. The environmental performance of a bioresource-based material depends on the characteristics of the feedstock, pretreatment requirements, material-conversion route, functionalization, application, and end-of-life (EOL) pathway [2,3]. In particular, energy demand, solvent use, chemical consumption, process yield, product durability, recyclability, biodegradability, and post-use recovery can substantially influence the overall sustainability of the system [4–6].

Recent reviews have demonstrated the increasing diversity of approaches for converting agricultural and food wastes into biodegradable materials and other value-added products. Bioresource utilization has been examined within broader biorefinery and circular-bioeconomy frameworks, including the production of bioplastics, biocomposites, functional materials, and chemical or biological intermediates [7–13]. These studies indicate that the technical potential of bioresources is strongly associated with their chemical composition, structural characteristics, and compatibility with downstream conversion processes. At the same time, pretreatment is often necessary to improve accessibility, remove undesired components, or modify the physicochemical properties of biomass before materialization. Reported approaches include mechanical, chemical, enzymatic, thermal, and combined treatments. The diversity of these approaches highlights the importance of selecting pretreatment conditions according to both feedstock characteristics and the intended material or application rather than treating pretreatment as an isolated processing step [7,9–11,13].

A further issue concerns the relationship between disclosed technological approaches and research needs. Patent documents provide evidence of claimed inventions and disclosed technical approaches, including specific feedstocks, processing conditions, material formulations, functional modifications, and applications. The scientific literature, in contrast, provides a broader basis for interpreting material mechanisms, processing limitations, sustainability considerations, environmental impacts, safety, and EOL requirements. Recent studies have also demonstrated the usefulness of combining patent and scientific-literature analyses to examine linkages between technological development and scientific knowledge [14–16]. Nevertheless, many reviews of bioresource-based materials remain organized primarily around individual feedstocks, material classes, or application areas. This organization is useful for summarizing the literature but can make it difficult to identify how different Technology Elements are connected across the overall material-development pathway.

From a circular-materials perspective, therefore, it is necessary to examine bioresource-based material development as an interconnected Technology Network rather than solely as a linear sequence from raw material to final product. Such a network can include bioresource selection and characterization, pretreatment, materialization, functionalization, application, and EOL or recovery. The network perspective is particularly relevant because a technically successful materialization step may not necessarily be associated with an efficient pretreatment process, a high-value functional application, or a defined post-use pathway. Likewise, the presence of a biodegradable or bio-based material does not automatically demonstrate lower environmental impacts without an appropriate sustainability assessment, such as life cycle assessment (LCA) [4–6].

Patent analysis can complement literature-based reviews in this context by revealing which technical elements are repeatedly implemented and which combinations of elements

occur less frequently within a defined technology corpus. Patent information is especially useful for identifying technical configurations through abstracts and claims, while the scientific literature can be used to interpret the scientific and sustainability-related implications of those configurations. Recent methodological studies have shown that large-scale text mining and ecosystem mapping can be used to examine linkages between patents and scientific publications [14,15]. In addition, recent reviews combining bibliometric, patent, and systematic approaches have demonstrated the value of integrating multiple evidence sources when characterizing emerging waste-derived biopolymer technologies [16–18].

Accordingly, the present study focuses on an evidence-based analysis of sustainable bioresource-based material alternatives using international patents and the scientific literature. Rather than experimentally developing or performance-testing a specific material, the study consolidates patent documents into Patent Families and organizes their technical evidence according to six Technology Elements: bioresource, pretreatment, materialization, functionalization, application, and EOL. The resulting evidence database is cross-checked with the relevant scientific literature to distinguish areas of technological concentration from Technology Elements that are relatively limited within the analyzed corpus. The study does not assign arbitrary scores or rank technologies according to a subjective opportunity index. Instead, research directions are derived from the intersection of patent-disclosed technical approaches and literature-based research needsThe objective of this approach is to provide a transparent basis for identifying research directions for sustainable bioresource-based material alternatives. In particular, the study examines whether current technologies are concentrated on material conversion while relatively fewer technologies connect pretreatment, functional performance, environmental and safety assessment, and EOL within an integrated Technology Network. By linking patent evidence with scientific evidence, the analysis aims to identify technically meaningful gaps and formulate research directions that are traceable to the underlying source data. This framework is intended to support future research planning without assuming that bioresource utilization is inherently sustainable and without extending the evidence beyond what can be supported by the analyzed patent and literature records. In this study, different search periods were applied to the scientific literature and patent documents according to their distinct information roles and analytical purposes. Recent scientific literature from the past five years was primarily reviewed to capture current research considerations, major research issues, technical limitations, and emerging sustainability-related research needs. In contrast, publicly available patent documents from the most recent 10-year period were examined to identify how scientific and technological developments have been reflected in disclosed technical approaches, including material production, functionalization, and applications. The final patent corpus comprised 34 Patent Families representing these disclosed technical approaches [19–52]. The different search periods were therefore not arbitrarily defined but were designed to capture recent research needs through the scientific literature and accumulated patent-disclosed technical approaches through patent documents as complementary sources of evidence.

Research Purpose

The purpose of this study is to systematically organize major bioresources and Technology Elements identified in international patents and the scientific literature, analyze their connections within a Technology Network, and identify relatively limited Technology Elements through evidence-based cross-checking. The study further seeks to derive research directions by comparing technical approaches disclosed in patent documents with research needs and sustainability considerations reported in the scientific literature.

2. Materials and Methods

2.1. Analytical Framework

The analytical framework distinguished technical approaches disclosed in patent documents from research needs identified in the scientific literature and subsequently cross-checked the two evidence sources (Figure 1). The contribution of this study lies not in proposing a new taxonomy or entirely new research directions, but in organizing patent-disclosed technical approaches and literature-derived research needs within a common six-element analytical framework. Patent analysis can reveal claimed inventions and disclosed technical approaches, whereas the literature provides complementary evidence concerning scientific principles, limitations, sustainability, safety, and EOL. By considering these evidence sources together through six Technology Elements and a Technology Network framework, this study presents areas that are more frequently represented in the analyzed corpus and areas for which direct evidence is relatively limited. The resulting research considerations are therefore derived from cross-source evidence rather than from subjective technology ranking or opportunity scoring. Patent documents were used to characterize specific technical configurations, including feedstocks, pretreatment, materialization, functionalization, application, and end-of-life. The scientific literature was used to interpret the characteristics of bioresources, the scientific principles underlying material production, sustainability considerations, environmental impacts, safety, and research needs and limitations associated with EOL.

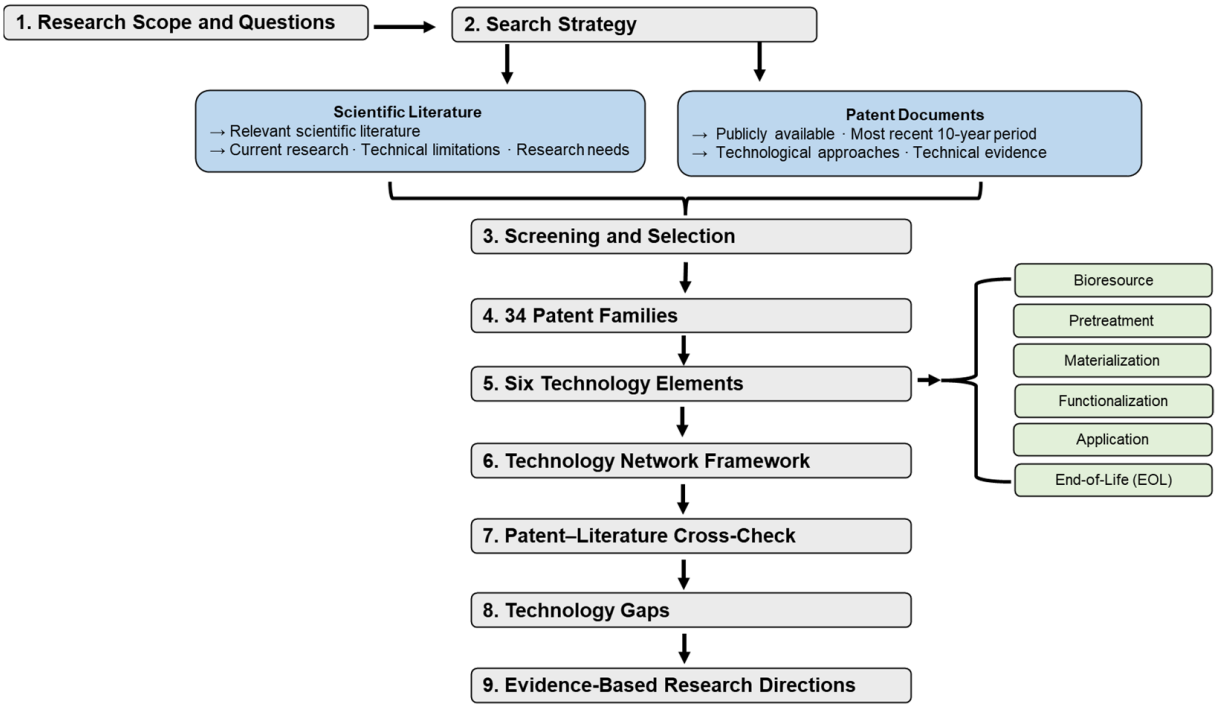


Figure 1. Overall research workflow for evidence-based patent–literature analysis and technology-network mapping. Arrows indicate the sequence of the analytical workflow and the connections between evidence sources and analytical stages.

2.2. Search Terms and Literature Search

The scientific literature search was conducted using Google Scholar in July 2026. The search strategy was developed around the core concepts of the research objectives, focusing on bioresource utilization, material development, and sustainability. Specific core keywords were initially used to identify relevant publications, and the search was subsequently expanded through combinations of related search terms, synonyms, and

associated technical terminology. Because the search was exploratory and iterative, no single fixed Boolean search string or standardized database field/filter combination was predefined or systematically recorded; therefore, the present study reports the core terms, search period, and screening criteria rather than retrospectively introducing an exact query string. The bioresource-related search terms included biomass, agricultural waste, food waste, agro-food waste, spent coffee grounds, fruit peel, bagasse, straw, and algae. Material-related terms included bioplastics, biodegradable polymers, biocomposites, functional materials, and carbon materials. Sustainability-related concepts, including bioresource utilization, biorefinery, circular bioeconomy, sustainable materials, life cycle assessment (LCA), safety, and end-of-life (EOL), were considered where relevant to the research scope. Retrieved publications were screened by examining their titles and abstracts to assess their relevance to the research objectives and the six analytical Technology Elements: bioresource, pretreatment, materialization, functionalization, application, and EOL. Publications were considered for inclusion when they substantively addressed bioresource utilization, material development, biorefinery, circular bioeconomy, sustainability assessment, safety, or EOL pathways and were relevant to at least one of the six analytical elements. Duplicate records and publications outside the defined material and analytical scope were excluded. Relevant foundational or methodological studies were retained when necessary to establish the technological background and interpret relationships between scientific research and disclosed technical approaches. Relevant studies published from 2016 to July 2026 were considered to understand accumulated research developments and the technological background. More recent publications were examined to identify current research considerations, technical limitations, sustainability-related issues, and potential future directions. No language restrictions were applied. The literature search and screening were designed to support a structured, evidence-based, technology-oriented review rather than a statistically exhaustive systematic review. The selected scientific literature was subsequently examined alongside publicly available patent documents from the most recent 10-year period to distinguish disclosed technical approaches from reported research needs and to derive evidence-based research directions (Table 1).

2.3. Construction of the Patent Family and Technology Element Evidence Database

Patent Family consolidation was performed at the invention and related-rights level rather than by counting each publication as an independent technology. Candidate patent records were compared using available bibliographic identifiers, including priority numbers and dates, application and publication numbers, applicant/inventor information, and documented family or continuation relationships. Records were consolidated when the available bibliographic information indicated the same Patent Family or a documented continuation, divisional, or equivalent relationship, and the technical subject matter was consistent with the study scope. The study did not apply a separate DOCDB- or INPADOC-specific family definition; instead, family relationships were based on the publicly available bibliographic and relationship information described above. For each Patent Family, one representative publicly available patent document was selected for presentation in the main text. Related family members and source-level evidence were retained in the supplementary evidence database to preserve traceability. Patent Family relationships were checked using KIPRIS, WIPO PATENTSCOPE, EPO Espacenet, and publicly accessible patent-document pages. The patent search covered the most recent 10-year public period available for the study (approximately July 2016–July 2026); an exact day-level patent search date was not systematically recorded. The final analytical corpus comprised 34 Patent Families (Table 2 and Supplementary Table S1). Patent Families cited in the Results and Discussion were selected as representative examples to illustrate relevant bioresource categories,

technical approaches, and Technology Element relationships; they were not selected as a ranked subset.

Table 1. Search, Patent Document Examination, and Database Construction Procedure.

Stage	Analysis Area	Method
1	Definition of core concepts	Bioresource, biobased materials, circular bioeconomy, waste valorization, sustainability, etc.; definition of key concepts
2	Search-term expansion	Expansion of synonyms, related terms, and technical terminology through preliminary searches
3	Literature search	Search of relevant review and research articles, primarily using Google Scholar
4	Patent search	Keyword-based candidate searches using KIPRIS, WIPO PATENTSCOPE, EPO Espacenet, and publicly accessible patent-document pages
5	Patent document examination	Title/Abstract/Claims and bibliographic information verification
6	Patent Family construction	Documents with the same invention or continuous rights relationship consolidated at the Patent Family level
7	DB construction	Family → Patent No. → Abstract/Claims → Feedstock → Pretreatment → Materialization → Functionalization → Application → EOL → Literature → Source Link
8	Literature–patent cross-check	Technical relevance and cross-check of research needs against the source evidence
9	Technology Network mapping	Structured from a network perspective based on connections among Technology Elements
10	Technology areas	Identification of relatively concentrated and less frequently documented relationships among Technology Elements to derive evidence-based research directions

Table 2. Summary of the Patent Family Corpus.

Analysis Area	Method
Final Patent Families	34
Analytical Elements	6
Representative Documents	34
Evidence Sources	KIPRIS, WIPO PATENTSCOPE, EPO Espacenet, and publicly accessible patent-document pages
Analysis	Patent–Literature cross-check

2.4. Technology Element Keyword Mapping and Technology Network Construction

The mapping results were reviewed against the source documents using the predefined Technology Element criteria. The initial mapping was conducted by the authors and reviewed for consistency against the source documents; no independent inter-coder reliability statistic was calculated because a separate independent coding procedure was not performed. The resulting family-level evidence matrix was used to identify documented relationships among the six Technology Elements and to organize them within the Technology Network framework. In this study, a "Technology Element" is one of the six predefined categories used to classify explicit technical content in the patent evidence: bioresource, pretreatment, materialization, functionalization, application, and EOL. A "Technology Gap" refers to a Technology Element or relationship that was relatively less frequently identified in the analyzed patent evidence under the predefined direct-evidence criteria; it does not indicate a field-wide absence. The term "Technology Network" refers to a structured

representation of relationships among the six Technology Elements and does not imply a formal graph-theoretical analysis based on centrality, density, or other network metrics. A Patent Family could be assigned to multiple Technology Elements when identifiable technical evidence supported each assignment. Where no direct evidence was identified, the element was recorded as "not identified in the analyzed patent evidence," rather than as absent from the broader field.

2.5. Generative AI Use

AI-assisted tools were used as supplementary aids during the research and manuscript preparation process. During the research workflow, the authors used ChatGPT (GPT-5.6 Luna, OpenAI, San Francisco, CA, USA; https://chatgpt.com/, accessed 23 October 2026) to support matching of the retrieved scientific literature and patent documents with predefined search terms and Technology Elements, preliminary classification and mapping of technical information, and exploration of potential secondary relationships among Technology Elements. ChatGPT was also consulted for preliminary consideration of research differentiation and potential originality, as well as for English language editing, grammar, spelling, sentence structure, and manuscript readability. AI-generated suggestions concerning technology mapping and research differentiation were not treated as independent evidence or definitive judgments. The authors reviewed relevant outputs against the original patent documents and the scientific literature and made the final decisions regarding classification, interpretation, research contribution, and conclusions. ChatGPT was not used to generate primary research data or independently establish the novelty, legal status, or validity of the findings. The authors take full responsibility for the accuracy, integrity, and content of the published article.

3. Results

3.1. Distribution of Major Bioresources and Technology Elements

Mapping the 34 Patent Families according to the Technology Element keyword framework (Table 3) repeatedly identified agricultural by-products, food and organic wastes, spent coffee grounds, fruit residues, and algal biomass as major bioresource categories (Table 4).Pretreatment and materialization were simultaneously identified in many Patent Families, whereas functional materialization and EOL-related technologies appeared selectively in specific Patent Families.

Table 3. Technology Element Keyword Mapping Framework.

Technology Element	Keyword Mapping Criterion	Source Evidence
Bioresource	Agricultural by-products, food and organic wastes, spent coffee grounds, fruit residues, algae, etc.	Abstract/Claims
Pretreatment	Drying, grinding, acid/alkaline, enzymatic, bleaching, thermal treatment, high-pressure and ultrasonic treatment, etc.	Abstract/Claims
Materialization	Films, textiles, composites, bioplastics, PHA/PHB, carbon materials, etc.	Abstract/Claims
Functionalization	Extracts, surface modification, additives, functional components, etc.	Abstract/Claims
Application	Packaging, cosmetics, textiles, environmental material, consumer products, etc.	Claims/Description
EOL	Biodegradation, recycling, anaerobic digestion, recovery, post-use carbonization, etc.	Claims/Description

Table 4. Summary of Technology Element Findings in the Analyzed Patent Families.

Technology Element	Main Observation
Bioresource	Agricultural by-products, food and organic wastes, spent coffee grounds, fruit residues, and algal biomass
Pretreatment	Drying, grinding, chemical, enzymatic, and thermal treatments
Materialization	Bioplastics, composites, fibers, functional materials, and carbon materials
Functionalization	Material-property improvement and functional components
Application	Packaging, cosmetics, textiles, environmental and consumer products
EOL	Direct evidence for integrated reuse, recycling, recovery, and post-use pathways was relatively limited

3.2. Relative Gaps Among Technology Elements

The relatively limited direct evidence for LCA, sustainability assessment, and safety should be interpreted in light of the purpose and disclosure structure of patent documents. Patent abstracts and claims primarily define technical subject matter and claimed or disclosed approaches; they do not necessarily report comprehensive environmental, life-cycle, or toxicological assessments. Accordingly, the present finding indicates that such assessment evidence was less frequently identified in the analyzed patent corpus, not that these topics are absent from the broader scientific literature or that the technologies are inherently unsustainable. The literature cross-check was therefore used to identify opportunities for more explicit integration of environmental and safety assessment with material development rather than to claim a field-wide research absence (Table 5). The scientific literature was examined as complementary contextual evidence rather than as a second quantitatively coded corpus. Accordingly, the literature–patent relationships were not intended to represent one-to-one documentary links between every Patent Family and individual publication; relationships were interpreted according to technical and thematic relevance.

3.3. Patent–Literature Cross-Check

When the technical approaches disclosed in patent documents were considered alongside research needs reported in the scientific literature, pretreatment and materialization technologies were found across a relatively broad range of Patent Families [19,20,24–26,28–32,34,36–40,45–52] (Table 6). In contrast, Technology Elements simultaneously connecting the environmental burden of pretreatment conditions, integrated functionality/environmental-performance/safety assessment, and EOL were relatively limited. This finding suggests that sustainability assessment of bioresource-based material alternatives should consider the connectivity of the overall Technology Network rather than focusing only on whether the feedstock is bio-based (Table 7).

Table 5. Distribution of Technology Elements and Relative Technology Gaps.

Category	Technology Element/Assessment Dimension	Number of Families with Direct Evidence	Representative Families	Observed Technical Characteristics	Relative Gaps/Limitations	Link to Research Strategy
Technology Element	Bioresource	28	F01/F07/F13/F18/F33	Diverse feedstocks, including agricultural residues, food wastes, spent coffee grounds, fruit peels, and algae, were identified.	Standardization, selection, and linkage based on feedstock characteristics are relatively limited.	Bioresource characterization and feedstock–technology matching
Technology Element	Pretreatment	26	F08/F11/F27	Multiple pretreatment methods were identified, including grinding, drying, alkaline and acid treatment, enzymatic treatment, bleaching, thermal treatment, and high-pressure/ultrasonic treatment.	Pretreatment conditions are fragmented by individual feedstocks and products, with limited comparison from low-energy, low-solvent, and integrated-process perspectives.	Low-energy, low-solvent pretreatment and feedstock-specific standardization
Technology Element	Materialization	31	F10/F13/F15/F21/F28	Diverse materialization pathways, including films, fibers, composites, PHA/PHB, and starch- and cellulose-based materials, were identified.	Materialization represents a concentrated patent domain, indicating the need to move beyond simple feedstock-to-material conversion toward integrated Technology Network connections.	High-value material platforms based on diverse bioresource residues

Table 5. *Cont.*

Category	Technology Element/Assessment Dimension	Number of Families with Direct Evidence	Representative Families	Observed Technical Characteristics	Relative Gaps/Limitations	Link to Research Strategy
Technology Element	Functionalization	18	F06/F24/F26/F33	Carbon materials/biochar, melanoidin nanomaterials, antioxidant and UV-related functions, and other functionalization cases were identified.	Functionalization technologies are concentrated in selected feedstocks and applications, while designs that simultaneously consider environmental performance and safety remain limited.	Integrated assessment of functionality, safety, and environmental performance
Technology Element	Application	27	F01/F13/F19/F26	Diverse applications, including packaging, cosmetics, textiles, environmental remediation, and molded products, were identified.	Applications are diverse, but evidence-based strategies linking application requirements with feedstock availability require further development.	Application requirements–bioresource–material linkage
Technology Element	EOL	8	F12/F22/F29/ F30/F31/F34	Anaerobic digestion, composting, biodegradation, and complete degradation were directly identified in selected technologies.	Relatively few of the 34 Patent Families directly address EOL Technology Elements, and connections to recovery, reuse, and recycling remain limited.	Integration of EOL, recovery, recycling, and LCA

Table 5. *Cont.*

Category	Technology Element/Assessment Dimension	Number of Families with Direct Evidence	Representative Families	Observed Technical Characteristics	Relative Gaps/Limitations	Link to Research Strategy
Cross-Cutting Assessment Dimension	LCA / Sustainability Assessment	0 *	—	Direct LCA-related Technology Elements were not identified in the key patent claims.	Environmental performance was generally not quantitatively connected to the patent-derived Technology Elements within the analyzed corpus.	Integration with LCA, TEA, and environmental-performance assessment
Cross-Cutting Assessment Dimension	Safety/Environmental Toxicity	0 *	—	Direct evidence of systematic safety and environmental-toxicity assessment was not identified as a Technology Element in the analyzed patent evidence in the key claims of the Patent Family database.	Connections between functional materials, environmental release, human-health effects, and ecological safety were not directly established in the analyzed patent evidence.	Integrated safety and environmental-toxicity assessment

* The 0 values do not indicate that LCA or safety assessment does not exist in the broader scientific or technological field. They indicate that direct evidence was not identified as a Technology Element in the analyzed patent claims. For the family-level frequencies, a Technology Element was counted only when the corresponding direct-evidence criterion was explicitly supported by the patent evidence used for the family-level analysis; broader descriptive mentions in the supplementary matrix were not automatically counted. Because a Patent Family may map to multiple Technology Elements, the counts are not mutually exclusive. Representative Families were selected as illustrative examples of recurring or particularly clear evidence discussed in the Results and Discussion, not as a ranked subset.

Table 6. Evidence Mapping of the Major Scientific Literature to Analytical Elements.

ID	Authors/Year	Representative Literature	Keywords	Role in This Study
L01	Rosenboom et al. (2022) [1]	Bioplastics for a circular economy	bioplastics; circular economy; end-of-life; recycling	Circular economy analysis framework
L02	Ranjbari et al. (2022) [2]	Biomass and organic waste potentials towards implementing circular bioeconomy platforms: A systematic bibliometric analysis	biomass; organic waste; circular bioeconomy; bibliometric; keyword mapping	Keyword-based technology landscape methodology
L03	Le et al. (2024) [4]	Sustainability assessment methods for circular bio-based building materials	sustainability; circular bio-based materials; LCA; end-of-life	Technology Gap/EOL evidence
L04	Bianchi et al. (2024) [3]	Circular bioeconomy: A review of empirical practices across implementation scales	circular bioeconomy; regional scale; implementation; monitoring	Evidence for bioresource-based strategies
L05	Motohashi et al. (2024) [5]	Measuring science and innovation linkage with large-scale text mining of scientific papers and patents	science–technology linkage; patents; scholarly papers; text mining	Literature–patent linkage methodology
L06	Lyu et al. (2020) [6]	Eco-system mapping of techno-science linkages	techno-science linkage; patent citation; mapping	Supporting evidence for literature–patent linkage
L07	Amobonye (2026) [13]	Bibliometric, patent, and systematic review of waste-derived biopolymers and natural functional agents in active and intelligent packaging	bibliometric; patent landscape; waste-derived biopolymers; circular economy	Previous integrated methodology most closely aligned with the present study
L08	Ezeorba et al. (2024) [9]	Recent advances in biotechnological valorization of agro-food wastes (AFW)	agro-food waste; biorefinery; bioconversion; circular bioeconomy	Bioconversion technology pathways
L09	Vigneswari et al. (2024) [10]	Turning agricultural waste streams into biodegradable plastic	agricultural waste; bioplastic; biorefinery; carbon neutrality	Agricultural by-products → materialization evidence
L10	Susetyo et al. (2025) [11]	Harnessing agro-food organic residues for biodegradable materials	agro-food residues; biodegradable materials; biocomposites; LCA	Biodegradable materials and implementation gaps
L11	Dalbanjan et al. (2024) [14]	Descriptive review on conversion of waste residues into valuable bionanocomposites	waste residues; bionanocomposites; conversion; circular bioeconomy	Waste → functional composite material evidence
L12	Ali et al. (2022) [7]	Biowastes for biodegradable bioplastics production and end-of-life scenarios in circular bioeconomy and biorefinery concept	biowaste; bioplastics; end-of-life; upcycling; downcycling	Integrated EOL evidence

Table 6. *Cont.*

ID	Authors/Year	Representative Literature	Keywords	Role in This Study
L13	Senga et al. (2024) [17]	Sustainable valorization of agricultural waste into bioplastic and its end-of-life recyclability for biochar production	agricultural waste; bioplastic; end-of-life; biochar; LCA	Circular EOL evidence
L14	Kour et al. (2025) [15]	Cellulose based bioplastics: A sustainable approach toward environmental safety	cellulose; agricultural waste; bioplastics; environmental safety	Cellulose-based material evidence
L15	Carvalho et al. (2025) [16]	Valuing agro-industrial waste in the development of sustainable food packaging	agro-industrial waste; biopolymers; packaging; circular bioeconomy	Application–Materialization evidence
L16	Khamis et al. (2026) [18]	Functional bioplastics from agricultural wastes: Precursor engineering, composite strategies, and sustainable packaging performance	agricultural waste; functional bioplastics; composites; packaging; bibliometric	Functionalization–Application–literature mapping evidence
L17	Ali et al. (2023) [12]	Bioplastic production in terms of life cycle assessment: A state-of-the-art review	bioplastic; LCA; sustainability; life cycle	LCA and sustainability assessment context
L18	Zaborowska and Bernat (2023) [8]	The development of recycling methods for bio-based materials—A challenge in the implementation of a circular economy: A review	bio-based materials; recycling; circular economy; EOL	EOL and recycling context

Table 7. Mapping of Key Claims, Evidence Database Entries, and Interpretation Levels.

Key Claim	Evidence Source	Level of Evidence	Location in Manuscript	Caution
Patent technologies are concentrated on materialization of agricultural, food, and organic wastes.	Supplementary Tables S1 and S2	Technology Element mapping across the 34 Patent Families	Results/Discussion	Expressed as distribution/concentration patterns within the analyzed corpus, not quantitative superiority
Pretreatment technologies comprise diverse chemical, physical, and biological methods.	Supplementary Table S2; patent source documents	Abstract/Claims	Results	Energy and environmental burdens not inferred without separate LCA evidence
Direct EOL-related technologies are concentrated in selected Patent Families.	Table 5; Supplementary Tables S1 and S2	Direct-evidence family mapping	Results/Discussion	Use “relatively less frequently identified” rather than “insufficient”
LCA, TEA, and safety assessment should be integrated alongside patent-derived Technology Elements.	Tables 5 and 6; the relevant source literature	Database-based analytical interpretation	Discussion	Presented as directions for further research

Table 7. *Cont.*

Key Claim	Evidence Source	Level of Evidence	Location in Manuscript	Caution
Bioresource-based research should connect feedstock, pretreatment, materialization, application, and EOL from a Technology Network perspective.	Table 5; Supplementary Tables S1 and S2	Integrated evidence-based interpretation	Discussion/ Conclusion	Actual volumes and economic characteristics of specific feedstocks require separate data

4. Discussion

A major contribution of this study is the cross-checking of technical approaches disclosed in patent documents with research needs reported in the scientific literature within a common evidence framework. Patents reveal claimed or disclosed feedstocks, processes, material formulations, and applications, whereas the scientific literature provides evidence for interpreting the scientific basis, technical limitations, and sustainability issues associated with these technologies. Accordingly, the research directions proposed here were not established as arbitrary technology-development ideas; they were derived from the intersection of the two evidence sources and from Technology Elements that were relatively limited in the analyzed corpus (Table 8).

Table 8. Technology Gaps, Supporting Literature, and Derived Research Directions.

Technology Gap	Patent Evidence	Role of Literature Evidence	Derived Research Directions	Basis of Research Direction
Pretreatment and materialization technologies are diverse, but life-cycle connections remain limited.	Pretreatment/ materialization across multiple Patent Families	Interpretation of research needs from sustainable-processing and biorefinery perspectives	Bioresource-specific integration of low-energy, low-solvent pretreatment and materialization	Derived from the intersection of the database and the scientific literature
Functional materials are represented, although integrated environmental-performance and safety assessment remains limited.	F03/F04/F23/F24/ F25/F26/F33, etc.	Need to strengthen sustainability and safety assessment of functional materials	Integrated assessment of functionality, environmental performance, and safety	Established as a direction for further research
Direct EOL technologies are concentrated in selected Patent Families.	F12/F22/F29/F30/ F31/F34, etc.	Need to strengthen circular-economy, EOL, and recycling research	EOL-linked design of bioresource-based material alternatives	Derived from the intersection of the database and scientific literature
Technology pathways are fragmented by bioresource.	Complex feedstock clusters including agricultural and food wastes, spent coffee grounds, fruit residues, and algae	Biorefinery and resource-upgrading literature	Customized linkage among feedstock characteristics, pretreatment, and materialization	Integrated database-based interpretation

4.1. Bioresource-Specific Pretreatment–Materialization Integration

Patent analysis identified diverse pretreatment technologies, including drying, grinding, alkaline and acid treatment, enzymatic treatment, bleaching, and thermal treatment.

However, approaches that simultaneously consider feedstock characteristics and final material requirements while optimizing energy use, solvent demand, and yield appear relatively limited compared with studies focused on individual pretreatment technologies. Future research should therefore investigate the relationships among bioresource composition and physicochemical properties, pretreatment conditions, and resulting material properties [9–11,14].

4.2. High-Value Functional Materialization of Bioresources

For spent coffee grounds and fruit residues, multiple technological pathways were identified beyond their use as feedstocks for bioplastics, including extraction products, melanoidins, and carbon materials. These pathways indicate opportunities for recovery of valuable components from a single bioresource and subsequent routing of residual fractions to other material applications. Future research should therefore consider integrated biorefinery approaches that connect major feedstock components with functional materials, polymeric or fibrous materials, and carbon-based materials [2,9,12].

4.3. Integrated Assessment of Functionality, Environmental Performance, and Safety

Compared with patents describing functional or property improvements, technical evidence quantitatively assessing environmental impacts and safety across both manufacturing and post-use stages was relatively limited. This observation does not imply that the technologies are unsustainable; rather, it indicates that quantitative evidence directly addressing these aspects was limited within the analyzed patent corpus. The scientific literature identifies LCA as an important approach for assessing the sustainability of bio-based materials and emphasizes the need to consider EOL scenarios and circularity [4,7,8,17].

4.4. End-of-Life-Linked Material Design

A further limitation is that the observed frequency of sustainability- and safety-related evidence may be influenced by patent disclosure practices and the selected search scope. Patent documents are not designed to provide complete LCA, techno-economic, or toxicological datasets. Thus, the identified evidence limitation should be interpreted as a limitation of what could be directly established from the analyzed patent documents, rather than a definitive measure of the amount of research conducted across the field. EOL-related technologies were identified in some Patent Families; however, cases linking material design from the outset to specific post-use pathways such as reuse, recycling, biodegradation, anaerobic digestion, or carbonization were relatively limited. Future research should therefore adopt a design-for-circularity approach that considers not only material production but also post-use recovery, recycling, and biological or thermochemical conversion pathways [1,7,8,18].

4.5. Overall Research Strategy

Taken together, the patent–literature cross-check indicates that future research on bioresource-based material alternatives should focus not only on the novelty of individual materials but also on strengthening the connections among Technology Elements. From a Technology Network perspective, these findings can be represented as a circular research structure in which feedstock characteristics, processing, material functions, applications, and EOL pathways are considered as interconnected components (Table 9).

4.6. Significance of the Study

This study is significant in that it distinguished technical approaches disclosed in patent documents from the interpretation of research needs in the scientific literature while cross-checking both evidence sources from a Technology Network perspective. The techni-

cal evidence from 34 Patent Families was structured according to predefined Technology Elements, and the scientific literature was used to supplement research needs related to sustainability and EOL. Research directions were consequently derived from evidence rather than from an arbitrary scoring or technology–opportunity system. The analysis focused on the presence and documented relationships of Technology Elements identified in the original source documents, thereby supporting transparent interpretation of the results.

Table 9. Evidence-Based Technology Network Strategy for Bioresource-Based Materials.

Research Stage	Key Direction	Major Evaluation Factors
1	Bioresource characterization	Composition, moisture, supply stability, feedstock variability
2	Low-burden pretreatment and targeted separation (process-level separation; not an independently coded Technology Element)	Energy, solvent, processing time, yield, and separation efficiency
3	High-value materialization and functionalization	Functionality, material properties, yield, and application performance
4	Technology Network linkage	By-product reuse, cascading utilization, and connections among Technology Elements
5	Environmental performance–safety integrated assessment	LCA, carbon emissions, toxicity, and human and environmental safety
6	EOL design	Reuse, recycling, biodegradation, recovery, carbonization
7	Integrated validation	Review of LCA, TEA, and Technology Network circularity

4.7. Limitations of the Study

First, the patent analysis was based on predefined search boundaries and selection criteria and therefore cannot be considered fully representative of the entire patent population for bioresource-based material alternatives. Second, patent documents describe technical scope and claimed or disclosed approaches but may not directly quantify energy consumption, economic performance, or environmental impacts at industrial scale. Third, the absence of a specific sustainability indicator in a patent document does not mean that the corresponding technology lacks sustainability-related considerations; in this study, such cases were interpreted as 'quantitative evidence not identified in the patent documents.' Fourth, some patent–literature links were based on thematic and technical relevance rather than direct citation relationships. Therefore, these links should not be interpreted as evidence of direct citation or intellectual dependence unless explicitly established.

5. Conclusions

In this study, international patents and the scientific literature were systematically analyzed to identify major Technology Elements and research directions for sustainable bioresource-based material alternatives. A total of 34 Patent Families were examined through their abstracts and claims, and Technology Elements covering bioresources, pretreatment, materialization, functionalization, application, and EOL were organized in an evidence database and cross-checked with the relevant scientific literature. Agricultural by-products, food and organic wastes, spent coffee grounds, fruit residues, and algal biomass were identified as major bioresource categories, with broad representation of conversion technologies for bioplastics, composites, functional components, and carbon materials. In contrast, technologies integrating pretreatment, multistage materialization, environmental and safety assessment, and EOL within a single Technology Network were

relatively limited. Future research should therefore integrate low-burden pretreatment, high-value functional materialization, integrated environmental and safety assessment, and EOL-linked material design from a Technology Network perspective. These research directions were derived not as subjective proposals but by cross-checking technical approaches disclosed in patent titles, abstracts, claims, and relevant bibliographic information with research needs reported in the relevant scientific literature.

6. Patents

No patents resulted from the work reported in this manuscript.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su182110794/s1, Table S1. Patent Family Evidence Database Based on Publicly Available Patent Documents; Table S2. Technology Element Matrix for the 34 Patent Families; Table S3. Patent Document Search and Verification Log; Table S4. Linkage Matrix of the 34 Patent Families, Technology Elements, and Scientific Literature; Table S5. Evidence Matrix by Technology Element.

Author Contributions: Conceptualization, J.Y.C. and H.K.A.; methodology, J.Y.C.; software, J.Y.C.; validation, J.Y.C. and H.K.A.; formal analysis, J.Y.C.; investigation, J.Y.C.; resources, H.K.A.; data curation, J.Y.C.; writing—original draft preparation, J.Y.C.; writing—review and editing, J.Y.C. and H.K.A.; visualization, J.Y.C.; supervision, J.Y.C.; project administration, H.K.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the Supplementary Material. Further inquiries can be directed to the corresponding author.

Acknowledgments: This research was supported by the Korea Institute of Industrial Technology (KITECH) Basic Project [Development and commercialization for clean hydrogen production/storage and CO_2 monitoring system in the field of industrial /EH260008]. During the preparation of this manuscript, the authors used ChatGPT (GPT-5.6 Luna, OpenAI, San Francisco, CA, USA) for keyword-based literature and patent matching, preliminary Technology Element mapping, exploration of potential secondary relationships, preliminary consultation on research differentiation and potential originality, and English language editing. The authors reviewed and evaluated the AI-assisted outputs against relevant source documents and literature and take full responsibility for the content, analyses, interpretations, and conclusions of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EOL	End-of-Life
LCA	Life Cycle Assessment
TEA	Techno-Economic Assessment
PHA	Polyhydroxyalkanoate
PBAT	Poly(butylene adipate-co-terephthalate)
PHB	Polyhydroxybutyrate

References

1. Rosenboom, J.-G.; Langer, R.; Traverso, G. Bioplastics for a circular economy. *Nat. Rev. Mater.* **2022**, *7*, 117–137. [CrossRef] [PubMed]
2. Ranjbari, M.; Shams Esfandabadi, Z.; Zanetti, M.C.; Scagnelli, S.D.; Siebers, P.-O.; Aghbashlo, M.; Peng, W.; Quatraro, F.; Tabatabaei, M. Biomass and organic waste potentials towards implementing circular bioeconomy platforms: A systematic bibliometric analysis. *Fuel* **2022**, *318*, 123585. [CrossRef]
3. Bianchi, M.; Cascavilla, A.; Diaz, J.C.; Ladu, L.; Blazquez, B.P.; Pierre, M.; Staffieri, E.; Yilan, G. Circular bioeconomy: A review of empirical practices across implementation scales. *J. Clean. Prod.* **2024**, *477*, 143816. [CrossRef]
4. Le, D.L.; Salomone, R.; Nguyen, Q.T. Sustainability assessment methods for circular bio-based building materials: A literature review. *J. Environ. Manag.* **2024**, *352*, 120137. [CrossRef] [PubMed]
5. Motohashi, K.; Koshiba, H.; Ikeuchi, K. Measuring science and innovation linkage with large-scale text mining of scientific papers and patents. *Scientometrics* **2024**, *129*, 2159–2179. [CrossRef]
6. Lyu, X.; Zhou, P.; Leydesdorff, L. Eco-system mapping of techno-science linkages at the level of scholarly journals and fields. *Scientometrics* **2020**, *124*, 2037–2055. [CrossRef]
7. Ali, S.S.; Elsamahy, T.; Abdelkarim, E.A.; Al-Tohamy, R.; Kornaros, M.; Ruiz, H.A.; Zhao, T.; Li, F.; Sun, J. Biowastes for biodegradable bioplastics production and end-of-life scenarios in circular bioeconomy and biorefinery concept. *Bioresour. Technol.* **2022**, *363*, 127869. [CrossRef] [PubMed]
8. Zaborowska, M.; Bernat, K. The development of recycling methods for bio-based materials—A challenge in the implementation of a circular economy: A review. *Waste Manag. Res.* **2023**, *41*, 68–80. [CrossRef] [PubMed]
9. Ezeorba, T.P.C.; Okeke, E.S.; Mayel, M.H.; Nwuche, C.O.; Ezike, T.C. Recent advances in biotechnological valorization of agro-food wastes (AFW): Optimizing integrated approaches for sustainable biorefinery and circular bioeconomy. *Bioresour. Technol. Rep.* **2024**, *26*, 101823. [CrossRef]
10. Vigneswari, S.; Kee, S.H.; Hazwan, M.H.; Ganeson, K.; Tamilselvan, K.; Bhubalan, K.; Amirul, A.A.; Ramakrishna, S. Turning agricultural waste streams into biodegradable plastic: A step forward into adopting sustainable carbon neutrality. *J. Environ. Chem. Eng.* **2024**, *12*, 112135. [CrossRef]
11. Susetyo, B.; Abdul Khalil, H.P.S.; Bairwan, R.D.; Wibowo, R.; Sam'un, M.; Rawi, N.F.M. Harnessing agro-food organic residues for biodegradable materials: Toward circular and sustainable solutions. *Bioresour. Technol. Rep.* **2025**, *32*, 102396. [CrossRef]
12. Ali, S.S.; Abdelkarim, E.A.; Elsamahy, T.; Al-Tohamy, R.; Li, F.; Kornaros, M.; Zuorro, A.; Zhu, D.; Sun, J. Bioplastic production in terms of life cycle assessment: A state-of-the-art review. *Environ. Sci. Ecotechnol.* **2023**, *15*, 100254. [CrossRef] [PubMed]
13. Amobonye, A. Bibliometric, patent, and systematic review of waste-derived biopolymers and natural functional agents in active and intelligent packaging. *Discov. Polym.* **2026**, *3*, 20. [CrossRef]
14. Dalbanjan, N.P.; Eelager, M.P.; Korgaonkar, K.; Gonal, B.N.; Kadapure, A.J.; Arakera, S.B.; Kumar, S.K.P. Descriptive review on conversion of waste residues into valuable bionanocomposites for a circular bioeconomy. *Nano-Struct. Nano-Objects* **2024**, *39*, 101265. [CrossRef]
15. Kour, M.; Chaudhary, S.; Kumar, R. Cellulose based bioplastics: A sustainable approach toward environmental safety—A review. *Sustain. Mater. Technol.* **2025**, *46*, e01694. [CrossRef]
16. Carvalho, A.C.F.; Ghosh, S.; Hoffmann, T.G.; Prudêncio, E.S.; Krebs de Souza, C.; Roy, S. Valuing agro-industrial waste in the development of sustainable food packaging based on the system of a circular bioeconomy: A review. *Clean. Waste Syst.* **2025**, *11*, 100275. [CrossRef]
17. Senga, R.; Nasr, M.; Fujii, M.; Abdelhaleem, A. Sustainable valorization of agricultural waste into bioplastic and its end-of-life recyclability for biochar production: Economic profitability and life cycle assessment. *Chemosphere* **2024**, *369*, 143847. [CrossRef] [PubMed]
18. Khamis, M.S.; Roslan, N.I.A.; Selvam, T.; Abd Rahman, N.M.M.; Wan-Mohtar, W.A.A.I.; Saufi, A.S.; Mustapa, N.L.S.; Osman, M.S.; Feisal, N.A.S.; Kamaludin, N.H.; et al. Functional bioplastics from agricultural wastes: Precursor engineering, composite strategies, and sustainable packaging performance. *Bioresour. Technol.* **2026**, *445*, 134082. [CrossRef] [PubMed]
19. Method of Preparing Bioplastics, Bioplastics Prepared Thereby, and Film, Sheet or Container Using the Same. KR102163344B1, 12 October 2020.
20. Libation Co., Ltd. Bioplastic Manufacturing System Using Pulp Natural Polymer. KR102719337B1, 21 October 2024.
21. Industry-Academic Cooperation Foundation; Sun Moon University. A Cosmetic Composition for Anti-Aging Comprising Extract of Coffee Grounds. KR20180097101A, 30 August 2018.
22. Industry-Academic Cooperation Foundation; Sun Moon University. A Cosmetic Composition Comprising Fermented Extract of Coffee Grounds. KR20180097102A, 30 August 2018.
23. Rafique Co., Ltd. Preparing Method for Cosmetic Composition Comprising Fruit Bark and Cosmetic Composition Manufactured by the Method and Cosmetic Comprising the Cosmetic Composition. KR20230133488A, 19 September 2023.
24. Kim, T.-G. Method for Manufacturing Carbon Materials Using Spent Coffee Ground. KR20210147481A, 7 December 2021.

25. Fu, D.K.; Li, J.H.; Wei, X.Y.; Chang, G.; Xia, W.; Cui, L.H. Bagasse Biodegradable Plastic and Preparation Method Thereof. CN106349669A, 25 January 2017.
26. Liu, C.G.; Ma, Y.Y.; Qin, R.C.; Wang, D.; Bao, N.Z.; Cui, X.J. A Kind of Bioplastic Film Using Corn Stalks as Raw Material and Preparation Method Thereof. CN116218013A, 6 June 2023.
27. Li, H.S.; Zhang, S.K.; Ai, S.Y. A Method for Resource Utilization of Peel Waste. CN117777318A, 29 March 2024.
28. Huang, R.L.; Su, R.X.; Han, C.Z.; Zhao, Y.X.; Liu, Z.H. A Biodegradable Composite Material Reinforced with Sugarcane Bagasse Fiber and Its Preparation Method. CN117736562A, 22 March 2024.
29. Li, Y.J.; Zhang, S.K.; Ding, S.H.; Li, H.S.; Ai, S.Y.; Shan, Y. A Method for Preparing Pectin-Cellulose Composite Bioplastic Based on Fruit Peel Waste. CN119751712A, 4 April 2025.
30. Shen, Z.; Zhang, Y.L.; Zhang, K. Method for Anaerobic Digestion of Kitchen Waste and Bio-Enzyme-Modified Starch-Containing Bioplastics. CN119736347A, 1 April 2025.
31. Xu, X.M.; Shao, G.Q.; Xu, D.; Wu, F.F.; Jin, Y.M.; Yang, N.; Xu, Z.J.; Lv, L.P.; Zhang, H.H. Biological Plastic Film and Preparation Method Thereof. CN118085364A, 28 May 2024.
32. Yang, K. Method of Producing Plant Biomass-Based Bioplastic. US20200247979A1, 6 August 2020.
33. Zhu, H. Natural Fiber Composites as a Low-Cost Plastic Alternative. US20220162801A1, 26 May 2022.
34. Mohanty, A.K.; Misra, M.; Zarrinbakhsh, N.; Muthuraj, R.; Wang, T.; Rodriguez-Uribe, A.; Vivekanandhan, S. Biodegradable Polymer-Based Biocomposites with Tailored Properties and Method of Making Those. US20180127554A1, 10 May 2018.
35. Stephanopoulos, G.; Currie, D.H.; Fortnam, K.J. Methods for Conversion of Food Waste to Chemical Products. US20160355849A1, 8 December 2016.
36. Iannuzzi, E. Method for the Preparation of Polyhydroxybutyrate. US20230119428A1, 20 April 2023.
37. Ghotra, A.; Arshad, Z.; Cheung, S. Textiles Derived from Food Waste and Processes of Making Thereof. US20240360272A1, 31 October 2024.
38. Koksal, H.B. A Method for Obtaining Plastic Admixture Material and Bioplastic Material from Bread Waste. US20240052066A1, 15 February 2024.
39. Bagnani, M.; Peydayesh, M.; Mezzenga, R. Bioplastics Based on Amyloid Fibrils and Biodegradable Polymers. US20240240022A1, 18 July 2024.
40. Mai, C.; Mai, K. Method for Producing Compostable Bioplastics. WO2026097174A1, 15 May 2026.
41. Scandolera, A.; Reynaud, R. Cosmetic Composition. WO2022194912A1, 22 September 2022.
42. Aroso, I.M.A.; De Sa Bessa, R.; Reis, R.L.G.D.; Akcay, A.; Medina, J. Coffee Melanoidin Nanoparticles and Nanofibers. WO2022268898A1, 29 December 2022.
43. Medina, J.P.; Akçay, A.A. Cosmetic Compositions Comprising Melanoidins. WO2021130349A1, 1 July 2021.
44. Ray, J.; Steigerwald, J. Spent Coffee Ground Biochar, Related Methods of Making, Environmental Remediation Systems, and Methods of Removing Contaminants from Solution. US20240228327A1, 11 July 2024.
45. Su, L.Q.; Wu, J.; Sun, R.Y. A Method for Enhancing the Permeability of Fruit Peel by Bioenzymatic Treatment. CN115956646A, 14 April 2023.
46. Shin, S.-H. Biodegradable Plastic Composition Using Wheat Straw. KR20250118054A, 5 August 2025.
47. Wang, H.J.; Cheng, Y.F.; Yu, Z.H.; Zhong, W. Bagasse Fiber/PHA (Polyhydroxyalkanoate) Completely-Degradable Composite Material and Preparation Method Thereof. CN112358712A, 12 February 2021.
48. Chen, M.Z.; Chen, J.J.; Shen, H.Y.; Yang, Y.J.; Zhang, H.P.; Xie, D. The Biodegradable Composite of a Kind of Bagasse Graft Copolymer Enhancing and Preparation Thereof. CN106280343A, 4 January 2017.
49. Jia, Z.X.; Shen, H.Y.; Xie, D.; Chen, M.Z.; Luo, Y.F. Modified Bagasse Strengthening PBAT/Starch Complete Biodegradation Composite Material and Preparing Method and Application Thereof. CN106433044A, 22 February 2017.
50. Kato, N. Algae-Based Bioplastics and Methods of Making. US20230323281A1, 12 October 2023.
51. El Semary, N.A. Algae-Based Plastic. US11820888B1, 21 November 2023.
52. Chowreddy, R.R.; Jan Myhre, O.; Lundquist, M.; Fredriksen, S.B.; Helland, I. Composition. EP3795623A1, 24 March 2021.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.