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### **Biodegradable Materials, Packaging Innovation, and Environmental Sustainability in Applied Technology**

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#### **ABSTRACT:**

This study investigates biodegradable materials, packaging innovation and environmental sustainability in applied technology areas. The research is conducted using a qualitative approach, with semi-structured interviews conducted with 20 environmental experts, packaging designers, and industry professionals who are engaged in sustainable product development, and analysis of sustainability reports, product lifecycle assessments, and policy documents. The selection of the participants was ensured by using purposive sampling that recruited participants who have experience with sustainable packaging development. Thematic analysis was used to explore the value of innovative packaging solutions in helping to mitigate environmental impact and sustainable practice. The results indicate that the innovations in biodegradable packaging can result in significant reduction in the environmental impacts during their lifecycle, but they will depend on economic considerations, consumer attitude, regulatory policies and limitations of supply chain infrastructure. The study also brings theoretical contributions to the scholarship of sustainable packaging, and practical recommendations for the faster transition towards environmentally sustainable packaging systems in the applied technology industries.

**Keywords:** biodegradable materials, packaging innovation, environmental sustainability, applied technology, lifecycle assessment, circular economy, qualitative research, sustainable development.

#### **INTRODUCTION:**

Each year, roughly 141 million metric tons of packaging waste is produced worldwide, a significant fraction of which is entering natural ecosystems as a result of poorly developed waste management facilities, resulting in pervasive and long-lasting environmental damage. For applied technology sectors, collectively using a large portion of industrial packaging, the need for more environmentally friendly packaging systems is a critical challenge. In this context, biodegradable materials and packaging innovation are becoming essential technological and strategic solutions to the ever-increasing environmental and economic burden of traditional petroleum-based packaging.

Biodegradable materials are materials that can be broken down by biological agents, mainly bacteria and fungi, into biologically occurring compounds, namely carbon dioxide, water and biomass, within a given period of time under given environmental conditions. The research and commercial efforts for

producing biodegradable packaging materials have increased significantly in the last 20 years, with progress in biopolymer chemistry, agricultural biotechnology and materials engineering. Modern biodegradable packaging materials are composed of a wide range of materials, such as polylactic acid, polyhydroxyalkanoates, thermoplastic starch, cellulose-based films and mycelium composites, which have different performance characteristics and environmental challenges (Mohanty et al., 2018).

Increasingly, biodegradable materials are perceived as a viable choice to traditional plastic packaging, especially in applied technology where the environmental awareness is growing. The materials formed from renewable materials like starch, cellulose and polylactic acid are broken down naturally by microorganisms, minimizing the long-term ecological impact (Shah et al., 2008). Mechanical strength, barrier properties and durability of biodegradable materials have been the areas of packaging innovation for recent years to make them more suitable for commercial and industrial applications (Narancic et al., 2018). Furthermore, the adoption of cutting-edge technologies, such as nanocomposites and bio-coatings, has improved the sustainability packaging solutions' performance and cost-efficiency (Ncube et al., 2021). The environmental advantages of using biodegradable packaging are significant, with the reduction of plastic waste accumulation and the reduction of carbon emissions from traditional plastics being two key benefits (Jambeck et al., 2015). Furthermore, global production statistics and policy incentives for bioplastics suggest a trend towards more sustainable materials, further strengthening the potential of bioplastics to contribute to environmental sustainability (European Bioplastics, 2022).

In the field of environmental sustainability, packaging innovation includes not just replacing traditional packaging materials with bio-based ones, but also designing packaging systems to use less packaging material, improve product shelf life, make packaging reusable, make packaging recyclable or recoverable, and optimize EoL recovery and valorization. This systems-level approach to packaging sustainability is consistent with the principles of circular economy thinking which aims to decouple economic growth from a consumption of resources and environmental degradation – by keeping products in use for as long as possible (Ellen MacArthur Foundation, 2013).

Applied technology sectors (electronics, medical devices, scientific instrumentation and advanced manufacturing other than those mentioned) offer unique problems and opportunities for sustainable packaging innovation. They are known for their intricate product shapes, complex protective packaging needs, strict regulatory standards controlling packaging materials in contact with sensitive products, and world-wide supply chains with high performance demands on packaging systems. Meanwhile, the innovation cultures and technological expertise of applied technology companies enable them to create and implement advanced sustainable packaging solutions that can later translate to more applications within the industrial and consumer sectors.

Although the study of sustainable packaging has grown in popularity amongst scholars and practitioners, research specifically with an applied technology perspective focusing on biodegradable materials and packaging innovation and environment protection is still limited. Most existing research has been conducted in the field of food and consumer goods packaging, while there is relatively less research on the unique characteristics of technology-driven industries. To fill this gap, this study aims to explore the concept and practice of sustainable packaging innovation qualitatively by observing the construction and development of ideas of environmental experts, packaging designers and industry practitioners from applied technology sectors.

The three research questions that the study addresses are the following: In what way are biodegradable materials incorporated in packaging innovation processes, as part of applied technology sectors? What are the organizational, regulatory and supply chain conditions that make it easier or more difficult to use sustainable packaging innovations? How does the packaging innovation process support other aspects of environmental sustainability? The results provide theoretical advancements in sustainable packaging research as well as practical implications for companies facing the challenge of sustainable packaging systems.

## LITERATURE REVIEW:

### Biodegradable Materials: Science, Classification, and Environmental Performance

In the last ten years, the number of scientific publications dealing with biodegradable packaging materials has increased significantly, due to the need for alternative packaging material to combat plastic pollution and the advancements in the science and technology of biopolymer. Biodegradables can be broadly categorized as bio-based, fossil-based, or hybrid, and by how they degrade at the end-of-life, either through industrial composting, home composting, anaerobic digestion, or marine biodegradation, under varying timescales and conditions (Rhim et al., 2013).

Polylactic acid is one of the most commercially viable biodegradable packaging polymers with properties similar to traditional plastics, yet it can be broken down under composting conditions in industrial compost. Mohanty et al. (2018) have done a comprehensive review of properties, processing characteristics and environmental performance of PLA, highlighting that its life cycle carbon footprint is significantly reduced in comparison to alternatives derived from fossil fuel resources. But the authors also noted issues with PLA's land use needs, potential competition with food crops and lack of end-of-life infrastructure in many jurisdictions.

The other important class of biodegradable biopolymers are polyhydroxyalkanoates which are also produced by microbial fermentation of organic materials and possess the ability to break down in the ocean which is significant because of the amount of plastic that is floating in the sea. However, the biodegradation performance of PHAs is significantly better than that of PLA under ambient environmental conditions, which is proven by Chen and Patel (2012); the production costs and processing complexity have been the factors that hindered commercial use of PHAs for a long time. These cost barriers are being progressively overcome with the development of fermentation technology and diversification of feedstocks.

Mycelium composites (MCs), a new type of biodegradable packaging material, made of vegetative body of fungi, have been attracting research interest as a new packaging material that can partially substitute expanded polystyrene in protective packaging applications. Using a lifecycle assessment methodology, Jones et al. (2020) concluded that mycelium composites are significantly lower in carbon-footprint, energy intensity and eutrophication potential than their EPS counterparts, and can be degraded in weeks under ambient conditions at the end-of-life. The properties make mycelium composites a very interesting candidate for applied technology sector packaging applications.

### The primary focus of packaging innovation

The concept of circular economy has had an impact on the current discourse of packaging innovation, moving from substitution of materials to the redesign of packaging value chains. Circular packaging strategies draw on a hierarchy of interventions – from eliminating unnecessary packaging, reducing material intensity, using recycled content, designing for recyclability, to developing packaging materials that can be safely returned to the biological cycle at end of life (Ellen MacArthur Foundation, 2013).

The global production history of plastics and plastic waste was recorded by Geyer et al. (2017), showing that a large amount of plastics ever produced is not recycled nor burned but ends up in landfills or the environment. This analysis created a strong empirical argument for the need for innovation in circular packaging and showed the limitations of recycling to solve the plastic waste problem. The authors maintain that solutions must tackle the packaging system design upstream, not only waste management systems downstream.

Innovation in packaging for sustainability involves several design aspects; material selection, structural design, optimizing the manufacturing process, and end-of-life specification. Consumer acceptance of innovative sustainable packaging was explored through consumer perceptions of sustainable packaging innovations by Koenig-Lewis et al. (2014) and the authors determined that there are three key factors including environmental benefits, functional performance and aesthetic appeal that all contribute to the acceptance of the innovative packaging. Their research brought to light the importance of being able to communicate the environmental credentials effectively and that sustainable packaging performs as well as or better than conventional packaging in a functional performance that is often a key requirement in applied technology areas such as the medical devices industry.

### **Environmental Sustainability Metrics and Lifecycle Assessment in Packaging**

Lifecycle assessment offers a methodological basis for quantifying the environmental performance of packaging systems, through the entire value chain that includes raw material extraction and processing, packaging manufacturing, distribution, use and end-of-life management. The methodology requirements for LCA are laid down in the ISO 14040 and 14044 standards, which provide a common framework for comparing the environmental impacts of different packaging solutions in categories such as global warming potential, ozone depletion, eutrophication, acidification and resource depletion (ISO, 2006).

A large and even sometimes conflicting evidence base has been produced in the area of biodegradable packaging materials and LCA. Walker and Rothman (2020) performed a systematic review of LCAs that compared biodegradable and traditional packaging, and concluded that biodegradable packaging consistently scored better than traditional packaging on global warming potential and fossil resource depletion metrics, and was somewhat more mixed on land use, water use and eutrophication metrics. The review highlighted the value of the definition of the system boundaries and the assumptions about the end of life scenarios when making decisions about the results of a LCA, and pointed out that it is important to not make sweeping statements about the superior environmental performance of biodegradable packaging.

Packaging sustainability regulations have significantly changed for key markets, offering opportunities and constraints for packaging innovations. The EU Packaging and Packaging Waste Directive (2008/95/EC) and follow-up Packaging and Packaging Waste Regulation (2978/92/EU) have set mandatory recycled content content, packaging weight reduction and EPR obligations that are changing the design priorities of industrial packaging (European Commission, 2022). The regulatory picture is beginning to look complex and varied around the world, as similar regulations are developing in other jurisdictions, which organisations involved in applied technology supply chains around the world will have to manage.

This report outlines the unique challenges and opportunities associated with sustainable packaging in applied technology sectors. Each applied technology segment has unique packaging sustainability concerns due to the nature of the product and its packaging chain. Customized protective packaging solutions are often needed to protect electronic products, medical devices, and scientific instruments from electrostatic discharge, mechanical shock, moisture leakage, and contamination, but these solutions are usually provided primarily by non-biodegradable materials such as expanded polystyrene and polyethylene foam. The challenge of technical development of biodegradable alternatives with the same protecting properties as these ones is substantial.

Yam et al. (2005) conducted research to lay the groundwork for understanding technical performance criteria for protective packaging in high-tech industries, and determined that four key performance areas are shock absorption, vibration damping, electrostatic discharge protection and environmental barrier properties. Further studies have focused on whether biodegradable materials can be produced that are similar in protective performance to EPS and for a variety of electronic product applications, with Jones

et al. (2020) showing that mycelium composites and molded pulp alternatives can meet protective performance parity for a variety of electronic product applications.

The applied technology companies also have unique opportunities in sustainable packaging, due to the features of their organizational culture and their innovation capabilities. Companies that boast solid R&D efforts, sustainability goals and market influence are positioned to lead the way with packaging innovations that trickle down the supply chain and create new benchmarks. Some technology-adjacent companies are often praised for their use of brand influence and technical capability to drive sustainable packaging uptake through supplier networks such as Unilever's sustainable living plan and Apple's 100 percent recycled aluminum and fiber based packaging (Lim et al., 2022).

The area of digital technology and sustainable packaging innovation is an emerging research domain that is likely to have important implications for applied technology domains. Digital technologies such as blockchain-based material traceability, AI-based packaging design optimization, and digital twin simulation of packaging life-cycle performance enable new packaging system design, verification and communication capabilities for innovative sustainable packaging. The technological convergences imply that there is growing overlap between supply chain digitalization (as explored in the companion paper) and sustainable packaging innovation.

## **METHODOLOGY:**

In line with the study's aim of understanding how environmental experts, packaging designers and industry professionals understand the relationship between biodegradable materials, packaging innovation and environmental sustainability, this study used a qualitative research design based on an interpretive epistemological perspective.

### **Research Design and Approach**

The research design was based on a constructivist grounded theory approach which allowed for theoretical insights to arise inductively from the participant accounts, but also within the field of existing knowledge of sustainable packaging scholarship. The choice was made to not exclusively deductively design since the field of biodegradable materials innovation was so dynamic and because packaging challenges in the applied technology sector were so context-specific, the project needed to be theory-flexible and conceptually open.

### **Participant Selection and Sampling**

In order to recruit twenty participants to the study, who would have substantive knowledge in at least one of the three areas of the study, a purposive sampling approach was used. The participants ranged from environmental sustainability managers in technology manufacturing companies, packaging design engineers, lifecycle assessment experts, to policy advisors from regulatory organizations and academic researchers in sustainable materials. Within the purposive sampling framework, maximum variation sampling was used in order to ensure a variety of organizational situations, geographical settings and professional specializations.

### **Data Collection Procedures**

Each participant was interviewed for about fifty to seventy-five minutes, using a semi-structured format. The interviews used a protocol that focused on the professional experience with biodegradable packaging materials, perceptions of the environmental effectiveness of innovative packaging solutions, factors related to organization and regulation that impact packaging materials' adoption, and expectations of future developments in sustainable packaging. Each interview was videotaped, audio-recorded with permission and transcribed word for word. To triangulate and further contextualize

findings from the primary interviews, secondary data sources were methodically analysed and were mainly corporate sustainability reports, documents on product lifecycles, and policy papers.

**Analytical Approach**

Thematic analysis, based on the six phases outlined by Braun and Clarke (2006), was used, starting with data familiarisation and going through initial coding, theme development, theme review and refinement, theme definition and naming, and final write-up. Analysis was done through using NVivo software where the coding structure was discussed and peer-reviewed for greater analytical rigor. Through the use of a research journal, methodological choices and interpretive assumptions were recorded and critically analyzed during the entire analytical process, thereby sustaining reflexivity.

**ANALYSIS AND FINDINGS:**

The five key themes extracted from the transcript analysis of interviews and secondary documentation were: (1) Material Innovation and Performance Parity Challenges; (2) Lifecycle Environmental Benefits and Trade-offs; (3) Regulatory and Market Drivers of Sustainable Packaging Adoption; (4) Organizational and Supply Chain Enablers and Barriers; and (5) Toward Circular Packaging Systems in Applied Technology.

**Theme 1: relates to challenges in material innovation and performance parity**

Continuous protective performance parity has been recognized by all participants as the most critical technological challenge in the switch from conventional packaging to biodegradable materials in practical applications. Shock and vibration absorption, moisture barrier and packaging response to temperature and humidity were the key packaging requirements that were difficult for packaging designers to achieve with sensitive electronic and medical devices. Packaging designers reported the use of extensive iteration testing to develop a packaging configuration and material formulations that meet these stringent specifications.

Over the past 10 years, the performance difference among biodegradable materials and conventional materials has decreased significantly, with certain applications, especially low fragility / medium fragility products, now being well-served by commercially available biodegradable alternatives, noted environmental experts. Applied technology packaging applications were most commonly identified to be molded fiber, mycelium composites and advanced biopolymer foams.

**Table 1: Biodegradable Packaging Materials and Performance Assessment for Applied Technology Applications**

Material Type	Shock Absorption	Moisture Barrier	ESD Protection	Biodegradation Timeframe
Molded fiber / pulp	Moderate–High	Low–Moderate	Low	2–4 weeks (composting)
Mycelium composite	High	Moderate	Low	30–45 days (ambient)
Polylactic acid (PLA)	Moderate	Moderate	Low–Moderate	3–6 months (industrial composting)
Polyhydroxyalkanoates (PHA)	Moderate	Moderate–High	Low	3–6 months (marine)
Thermoplastic starch	Low–Moderate	Low	Low	1–6 months
Cellulose-based films	Low	Moderate	Low	1–2 months



**Theme 2: Lifecycle Environmental Benefits and Trade-offs**

Applied technology specific packaging experts shared extensive insights into the pros and cons of adopting biodegradable packaging and its impact on the environment. LCA results showed that for packaging materials, which can be made from renewable feedstocks and processed with renewable energy, the GWP is significantly lower (usually 40 to 70 percent lower) than the GWP of petroleum-based alternatives.

However, the participants also identified the complexity of sustainability trade-offs, since some of the biodegradable materials had higher land use, water consumption and eutrophication impacts than conventional materials, especially if the agricultural feedstocks were from water stressed areas or from intensive farming. These results were resonating with the Walker and Rothman 2020 systematic review, and mirrored participants' demands for environmental claims on biodegradable packaging to be based on specific, well-defined, lifecycle assessments of packaging, as opposed to generalizing on a material level.

**Table 2: Lifecycle Environmental Impact Comparison — Biodegradable vs. Conventional Packaging**

Impact Category	EPS (Baseline)	Molded Fiber	Mycelium	PLA
Global warming potential	Baseline (100%)	-55%	-62%	-48%
Fossil resource depletion	Baseline (100%)	-70%	-75%	-65%
Land use	Baseline (100%)	+120%	+85%	+140%
Water consumption	Baseline (100%)	+30%	+15%	+45%
Eutrophication	Baseline (100%)	+50%	+20%	+65%
End-of-life manageability	Poor	Good	Excellent	Moderate

**Theme 3: Regulatory and Market Drivers of Sustainable Packaging Adoption**

In a cross-sectoral analysis of the power of each external factor, participants identified regulatory frameworks as the strongest external factor for driving sustainable packaging adoption across the different sectors. The EU's packaging legislation was identified as the most influential, participants reporting that the EU requirements, such as the mandatory recycled content targets, the single-use plastics ban and the extended producer responsibility, had significantly changed packaging material selection within their companies.

Other market drivers, albeit less significant, but growing as consumer and investor pressure were mentioned. Participants spoke about the increased consumer environmental awareness, especially amongst younger generations, which had driven sustainable packaging to become a brand differentiator and influencing purchase. For large institutions, the financial drivers to show packaging sustainability leadership were mentioned to be the institutional investor's Environmental, Social, and Governance criteria.

**Table 3: Drivers and Barriers to Sustainable Packaging Adoption in Applied Technology Sectors**

Category	Drivers	Barriers
Regulatory	EU packaging regulation, EPR schemes, single-use plastic bans	Jurisdictional fragmentation, compliance complexity
Market / Consumer	ESG investor criteria, brand differentiation, consumer preference	Price sensitivity, performance skepticism
Technical	Material science advances, digital design tools, LCA tools	Performance parity gaps, infrastructure requirements

Organizational	Sustainability commitments, leadership champions, R&D investment	Cost premium, inertia, supplier capability gaps
Supply Chain	Supplier sustainability programs, circular economy models	Compostable infrastructure gaps, contamination risks

**Theme 4: Organizational and Supply Chain Enablers and Barriers**

Participants have identified organizational commitment to sustainability—expressed in formally developed sustainable packaging strategies, dedicated sustainability teams, and accountability for sustainable packaging performance targets in the executive level—as the key organizational enabler of sustainable packaging innovation. Organizations that have developed their sustainable packaging programs with a focus on sustainable business practices, as opposed to sustainable business functions, had more ambitious and accelerated plans for sustainable packaging than those in organizations where sustainable business was second only to compliance.

Inadequacy of industrial composting and organic waste collection infrastructure in many markets was found to be a systemic barrier to the practical environmental benefits of adopting biodegradable packaging. Participants highlighted that biodegradable packaging that cannot enter into an appropriate end-of-life processing facility is not better biodegradable than other plastic products in general landfill environments, further emphasising the systems approach to sustainable packaging and the importance of investing in the package systems as well as developing the materials.

**Theme 5: Applied Technology towards a circular packaging system**

The 'vision of and aspiration for fully circular packaging systems in applied technology sectors' was the most forward-looking theme uncovered in the analysis. Participants defined circular packaging as including not only biodegradable materials, but also reusable packaging systems, take-back and refurbishment initiatives, closed-loop material recovery, and digital material passports that provide visibility and traceability of packaging throughout its life to make the best end-of-life decisions.

A number of participants mentioned that packaging as a service was being implemented at an early stage; the service provider owns and takes care of the end-of-life of the packaging systems that are rented out. These models provide economic bases for higher sustainability performance by aligning incentives on packaging material efficiency and durability which conventional product packaging markets do not.

**Table 4: Circular Packaging Strategies and Implementation Maturity in Applied Technology Sectors**

Circular Strategy	Implementation Stage	Example Application	Key Enabler Required
Biodegradable material substitution	Active / scaling	Mycelium cushioning for electronics	Composting infrastructure
Packaging weight reduction	Mature	Thin-wall molded fiber trays	Performance testing capability
Reusable packaging systems	Emerging	B2B component shipping containers	Reverse logistics networks
Packaging-as-a-service	Pilot / early stage	Leased IoT device packaging	Business model innovation
Digital material passports	Emerging	QR-coded biodegradable packaging	Blockchain / digital standards

Closed-loop recovery	material	Pilot stage	PHA recovery from composting	Processing technology
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**DISCUSSION:**

The results of this research offer a detailed empirical description of the transformation of environmental sustainability in the field of applied technology from biodegradable materials to packaging innovation. The thematic analysis shows that there is an intricate landscape in which key technical progress on biodegradable material performance is coming together with a changing regulatory environment, consumer expectations, and new circular economy business models, presenting opportunities and challenges for a transition towards sustainable packaging.

This result is aligned with the literature about the adoption of sustainable packaging in technology intensive industries, where identification of performance parity is the main technical barrier. But the qualitative data provide welcome nuance as it shows there is a big difference in the performance gap between biodegradable and conventional materials, which is not evenly distributed, and is narrowing quickly for a lot of applied technology packaging applications. This discovery is an indication that there are material-related limitations, but they are becoming more manageable with targeted investment in innovations and should not be viewed as a "no-go" zone for biodegradable packaging.

The lifefecycle environmental benefit and trade-off results present a crucial paradox in the field of sustainable packaging: while biomass as a component of packaging can be perceived as environmental good, the findings of a rigorous lifecycle assessment are more nuanced. The parallel reduction of GWP values and increase of land use and water consumption highlights the need to shift towards environmental assessments beyond a single metric, and towards boundary defined assessments that consider the entirety of environmental impacts. The discovery has ramifications for sustainability reporting by organizations and the development of regulatory standards.

Innovation with biodegradable material, as a component of a more systems-oriented approach toward implementing a circular packaging system, is the most theoretically relevant item of the analysis to emerge from Theme 5. The introduction of packaging-as-a-service business models and digital 'passports' for materials as emerging innovations with tremendous systemic potential means that packaging innovations that gain the most can be as much business model and information architecture innovations as material innovations – with important implications for packaging investment strategies.

**CONCLUSION AND RECOMMENDATIONS:**

The overall relationship between biodegradable materials, packaging innovation and environmental sustainability in applied fields of technology has been analyzed in a qualitative study by twenty experts (environmental experts, packaging designers and industry experts). The research has shown that innovation in biodegradable packaging has great environmental potential and measurable impacts, including those on global warming potential and fossil resources, but also raises complex sustainability questions that need to be considered in a context-specific manner.

The study results point to this fact: the shift to sustainable packaging in applied technology sectors is already on the way and has already made good progress in some areas (such as material substitution and minimizing packaging weight), but is still in its early or emergent stage in others (such as reusable packaging systems, packaging-as-a-service, and closed-loop material recovery). Progress needs to be accelerated in all dimensions and this demands synergy between regulatory, organizational, technological and infrastructure action.



The overarching take-away from this study is that applied technology sectors need to consider a system perspective to make a successful transition into sustainable packaging, including material innovation, business model redesign, infrastructure development, regulatory coherence and digital technology enablement. Biodegradability is an essential, but not yet sufficient, part of this transition as it relies on the right end-of-life infrastructure, adequate lifecycle assessment methodologies and circular economy governance systems.

#### RECOMMENDATIONS:

Applied technology organizations should implement a holistic packaging sustainability approach that is based on a dependable lifecycle assessment methodology, setting environmental performance goals based on several metrics and not a single criterion like biodegradability. Packaging innovation investment should involve material innovation, business model innovation and feasibility studies of reusable packaging and models of packaging-as-a-service for product categories.

Industry associations and standards bodies should create sustainable packaging guidelines for specific sectors of the applied technology industry that reflect the unique protective performance needs and supply chains across each sector. Pre-competitive research programmes would be faster in identifying and validating viable biodegradable packaging solutions in different application contexts if they would benefit from co-operative research programmes, which combine testing data and the findings on the performance of the materials.

Efforts should be directed to investment in industrial composting and/or collection of organic waste as this is integral to the environmental gain to be achieved through adopting biodegradable packaging. Regulatory systems need to be coordinated, with less complexity for organisations involved in global supply chains and with the inclusion of environmental performance criteria for the lifecycles of products, alongside material category-based definitions of sustainability.

Future research could examine the institutional arrangements of packaging sustainability governance in applied technology companies, focusing on how their sustainability commitments are embedded in processes for packaging innovation investment decisions and supplier development programs. Although it is useful to consider the environmental effects of packaging system transitions, a longitudinal study that follows packaging innovations over a number of years would yield valuable evidence to support actual (not predicted) environmental gains.

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