

# MATERIALS SCIENCE AND MECHANICS OF MACHINES

## ADVANCING SUSTAINABILITY IN FOOD PACKAGING: AN OVERVIEW OF BUSINESS STRATEGIES AND TRENDS

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### Abstract

This research paper provides an in-depth analysis of the evolving landscape of sustainable food packaging, driven by increasing consumer demand and stringent regulatory requirements. It explores key trends in sustainable packaging, including the adoption of recycling initiatives, innovative materials, and advanced design techniques. Additionally, the paper discusses the emerging circular bioeconomy approach, which emphasizes a cradle-to-cradle model to optimize sustainability at every stage of the packaging lifecycle. Certifications and standards are also addressed as essential tools for ensuring transparency and promoting environmentally responsible practices in the packaging industry. By analyzing the strategies employed by leading companies, this paper sheds light on the current state of sustainable food packaging and offers insights into future developments in this crucial area.

**Keywords:** Sustainable food packaging, Sustainable business strategies, Renewable materials, Circular bioeconomy, Sustainable Packaging.

### 1. Introduction:

Food packaging has always been essential for ensuring the safe distribution of products throughout modern supply chains. It plays a vital role in society by safeguarding food and food products from potential damage and degradation, maintaining safety and hygiene, and actively reducing food waste. With over 30% of food produced ending up in landfills due to spoilage during transportation or harvesting, effective food packaging is crucial for minimizing and preventing food waste [1]. As sustainability becomes a central

concern, the food industry must prioritize investments in areas like food packaging. When choosing packaging materials, it is important to select those that do not compromise human health, contribute to landfill waste, are recyclable or reusable, and do not emit greenhouse gases [2]. The packaging material must also resist moisture changes, microbial contamination, and gas permeability [3,4]. The Sustainable Packaging Coalition (SPC) lists eight criteria for Sustainable Packaging as shown in Table 1 [5].

Table 1.

Criteria defined by SPC for Sustainable Packaging

Criteria	Criteria Description
1	Beneficial, safe, and healthy for individuals and communities throughout its life cycle.
2	Meets performance and cost criteria in the market.
3	Sourced, manufactured, transported, and recycled using renewable energy.
4	Utilizes renewable or recycled source materials.
5	Manufactured with clean production technologies and best practices.
6	Made from materials that are healthy throughout their life cycle.
7	Designed to optimize the use of materials and energy.
8	Effectively recovered and utilized in biological or industrial closed-loop cycles.

### 1.1 Types of Food Packaging:

Packaging materials are crucial for product quality, presentation, and preservation, as they influence customer confidence and effectively communicate information. In this section, we discuss the types of most popular food packaging materials:

I. **Plastics:** Petroleum-based polymers like polyethylene, polypropylene, and polyester are widely used in packaging due to their good barrier properties, lightweight nature, and low cost, making plastics the most common packaging material [6]. However, their extensive use poses significant environmental challenges, including CO<sub>2</sub> emissions during production and pollution from improper disposal, leading to plastic waste in landfills and oceans. The European Union aims to re-

duce plastic waste by 55% by 2025 and ensure all materials are 100% recyclable or reusable by 2030, prompting a shift towards sustainable alternatives like biodegradable materials [7]. Biodegradable polymers, derived from natural, microbial, or chemical sources, are being explored to address these environmental concerns [8].

II. **Paper and Paperboard:** Paper and paperboard are widely used in packaging across various industries due to their sustainability and cost advantages over plastics, metals, and glass [9]. However, they have limitations, such as low resistance to water, chemicals, and strength. To overcome these issues, coatings like plastic or aluminum are often applied to enhance moisture resistance and durability. Despite these limitations, pa-

per-based packaging is gaining popularity as a more environmentally friendly alternative to plastics, especially with ongoing improvements and growing environmental concerns [10]. Coated paperboard is commonly used for packaging products, including those that may be microwaved, with careful selection of coatings to prevent harmful chemical reactions during heating [11].

III. Glass: Glass remains an important material in packaging, particularly in the food and pharmaceutical industries, due to its advantages in safety, preservation, and resistance to chemical attacks [12]. Despite other industries shifting to plastics and metals, glass continues to be favored for maintaining the quality and sensorial attributes of products. Glass containers, made either from recycled glass or by melting a mix of silica, sodium carbonate, and limestone, can be molded into various shapes and sizes, often used to convey messages to consumers [13–15]. Although the use of glass in packaging is declining, it remains one of the safest and most reliable materials, especially in the food and beverage sectors.

IV. Metal: Metal-based packaging materials, particularly aluminum, are widely used due to their properties like low cost, lightweight, recyclability, and high heat resistance [16]. However, safety concerns arise from the potential interaction between the packaging and its contents, requiring regular risk assessments to ensure consumer safety. Aluminum is the most commonly used metal for packaging, often in the form of cans and foil, though it can sometimes leach trace metals into the content if corroded [17]. Other metals like tin, lead, and chromium are also used in packaging, but each comes with specific health risks, particularly lead and chromium, which are toxic at high levels. Regulations, especially in the EU, limit the amount of these metals in food packaging to protect consumers from potential harm [18].

## **2. Key drivers of Sustainable Food Packaging in Businesses:**

This section explores the driving forces behind the adoption of sustainable packaging, focusing on consumer demand and regulatory requirements. It highlights how growing environmental awareness and evolving regulations are influencing companies to embrace eco-friendly packaging solutions, while also addressing the complexities and variations in consumer perceptions and legislative frameworks across different regions:

I. Consumer demand: The growing awareness of environmentally friendly packaging, driven by media influence, has led to a positive reception of socially responsible companies by most consumers [19]. Research indicates that consumer pressure plays a significant role in encouraging large companies to adopt sustainable packaging practices [20]. Factors influencing the purchase of sustainable packaged products include lifestyle, retailer reputation, product origin, price, and packaging type. However, consumer perceptions of

sustainable packaging, particularly in emerging markets, remain unclear, suggesting a need for companies to better understand and communicate these perceptions [21]. Studies show that consumers' environmental concerns, packaging design, and end-of-life attributes like recyclability and biodegradability are critical factors in purchase decisions [22]. Younger consumers, especially in Europe, prioritize the sustainability of packaging materials [23,24]. Willingness to pay more for sustainable packaging varies, influenced by factors such as altruistic and egoistic values, environmental commitment, and budget constraints [25]. Different regions, including Romania, China, and India, show diverse factors driving consumer interest in green packaging, with economic and functional values playing key roles [26–28].

II. Regulatory requirements: Numerous countries have implemented regulations that promote and mandate environmentally sustainable packaging while aligning with local cultural contexts. The maturity of these regulations varies widely across nations. These laws typically address comprehensive issues, including packaging requirements, recyclability, principal uses of packaging, and the entire packaging chain, from collection and sorting to setting reuse or recycling goals. In recent years, regulations have increasingly targeted plastic packaging due to challenges like the need for adequate barriers in food packaging, the economic viability of composting systems, and the limited economic value of compostable packaging. A detailed overview of sustainable food packaging regulations across different countries in [29] highlights diverse approaches to environmental conservation, including bans on single-use plastics, recyclability regulations, and extended producer responsibility (EPR) mandates.

## **3. Incorporating Sustainability in Business Strategies:**

In recent years, the drive toward sustainability has significantly influenced the food packaging industry, leading to the emergence of innovative solutions aimed at reducing environmental impact. In this section, we review few key trends in sustainable food packaging:

I. Recycling: Recycling is a key component of sustainable packaging, but challenges persist in improving recycling rates and efficiency. Paper and paperboard have relatively high recycling rates, though each cycle reduces fiber length and material strength, necessitating improvements in processes like deinking [30]. In contrast, plastic packaging recycling is more complex due to difficulties in separating different materials and components. Future trends in sustainable packaging will likely focus on designing plastics for better recyclability, such as using fewer materials, avoiding pigments, and ensuring all components of a package are recyclable [30]. Additionally, innovations like plastic-digesting bacteria and chemical recycling may further contribute to more sustainable packaging solutions.

Table 2

## Examples of companies actively investing in recycling

Company	Recycled food packaging initiatives
Nestlé	Uses recycled PET (rPET) in the packaging of several bottled water brands.
Unilever	Implements 100% recyclable packaging for its ice cream brands, including using rPET.
Coca-Cola	Has committed to using 50% recycled material in its bottles by 2030, already using rPET in many products.
PepsiCo	Utilizes rPET in beverage bottles and is transitioning to 100% rPET packaging in certain markets.
McDonald's	Introduced packaging made from recycled content, including recycled paper and fiber-based materials.
Danone	Uses rPET in the packaging of its water brands and dairy products.
Mars, Inc.	Committed to using 100% recyclable, reusable, or compostable packaging by 2025, including recycled content in food wrappers.
Starbucks	Uses recycled paper for coffee cup sleeves and is exploring options for recyclable cups.
Kraft Heinz	Introduced recycled plastic packaging in some of its ketchup bottles and is working on expanding it to other products.
General Mills	Uses recycled paperboard in its cereal boxes and is working towards more sustainable packaging across its brands.

II. Innovative Materials: New and higher-performing bioplastics are emerging as disruptive technologies in sustainable packaging, with ongoing research and development in this field. Innovations include bioplastics derived from bacteria and cellulose-based feedstocks like agricultural waste, as well as polycarbonate made from orange peel extracts and carbon dioxide [31]. Cellulose nanomaterials (CNs) are particularly

promising, offering versatility as barrier films, coatings, or reinforcement for plastics. PLA/CNC nanocomposite films have shown potential for extending the shelf life of water-sensitive foods [32]. Additionally, edible packaging is being explored, such as casein-based oxygen barriers and edible films reinforced with cellulose whiskers, offering innovative solutions for sustainable packaging [33,34].

Table 3

## Examples of companies actively using innovative materials

Company	Sustainable food packaging materials
Tetra Pak	Uses plant-based polymers and paperboard to create fully renewable packaging solutions.
Amcor	Develops high-barrier films made from bio-based materials for food packaging.
Mondi	Produces sustainable paper-based packaging that is 100% recyclable and biodegradable.
Sealed Air	Innovates with plant-based food packaging that reduces carbon footprint and is fully compostable.
Smurfit Kappa	Utilizes renewable and recycled materials in corrugated packaging, focusing on sustainability.
Stora Enso	Develops fiber-based packaging solutions as alternatives to plastic, reducing environmental impact.
Ball Corporation	Uses metal packaging that is infinitely recyclable, with a focus on sustainability and innovation.
AptarGroup	Creates closures and dispensing systems using biodegradable and compostable materials.
Sonoco	Innovates with packaging made from recycled content and alternative fibers.
WestRock	Develops fiber-based packaging solutions, including paper-based food containers and trays.

III. Design: Active packaging, which uses sensors or indicators to monitor the condition of packaged food, is expected to grow significantly [35]. These systems can include tags or labels embedded in packaging that either have direct contact with the food or interact with the surrounding atmosphere to provide information about freshness, quality, and safety. Examples include indicators that change color to show ripeness or freshness, such as a bromophenol blue indicator for guavas

or a biosensor film for shrimp [36,37]. Additionally, active packaging that extends shelf life through moisture absorption, carbon dioxide scavengers, or antimicrobial agents is being developed [38]. Another trend is lightweighting packaging to reduce raw material use and shipping costs, while still maintaining packaging performance to ensure products reach consumers in prime condition.

Examples of companies investing in sustainable packaging designs

Company	Sustainable food packaging design
Avery Dennison	Develops smart labels and indicators that monitor freshness and quality in food packaging.
Mondi	Produces packaging with active properties like moisture control and antimicrobial agents to extend shelf life.
Amcor	Innovates with packaging that includes oxygen scavengers and light protection to preserve food quality.
Smurfit Kappa	Uses lightweight and sustainable materials in packaging to reduce environmental impact and transportation costs.
Stora Enso	Creates fiber-based packaging solutions with embedded sensors for monitoring food safety and quality.
Sealed Air	Develops active packaging that incorporates moisture absorbers and carbon dioxide scavengers for better preservation.
AptarGroup	Focuses on closures and dispensing systems that enhance product shelf life and reduce waste.
Sonoco	Innovates with recyclable and lightweight packaging that still maintains the performance needed for food safety.
WestRock	Produces packaging solutions that combine sustainability with smart features like freshness indicators.

IV. Circular bioeconomy: The circular bioeconomy is a new approach to sustainability, emphasizing a cradle-to-cradle model that optimizes each step of the process rather than focusing solely on materials. This concept impacts sustainable packaging by incorporating innovative materials, design improvements, and enhanced recycling methods. For cellulose-based packaging, this includes sustainable sourcing, using residues and waste, developing bio-based products, prolonging

product use, and ensuring energy recovery, composting, and recycling. The circular bioeconomy also aims to reduce reliance on petroleum-based plastics by promoting a closed-loop system where plastics are reused and recycled rather than discarded. The Ellen MacArthur Foundation suggests transitioning to this model by drastically reducing virgin plastic use and shifting remaining inputs to renewable, responsibly managed sources [39].

Table 5

Examples of companies actively incorporating Circular Bioeconomy principles

Name of Company	Details of How the Company is Using Circular Bioeconomy
Stora Enso	Produces fiber-based packaging from sustainably sourced wood, promoting recycling and energy recovery.
Smurfit Kappa	Utilizes circular bioeconomy principles by turning waste into resources and promoting closed-loop recycling in paper packaging.
Mondi	Creates packaging solutions using recycled materials and sustainable fibers, emphasizing waste reduction and recyclability.
Amcor	Incorporates circular economy principles in packaging by using recycled content and designing for recyclability.
Danone	Utilizes bio-based packaging materials and promotes closed-loop recycling in its product lines.
L'Oréal	Develops packaging that incorporates recycled plastics and promotes refillable packaging systems.
Ikea	Develops packaging using renewable and recycled materials, emphasizing circularity in product design.
Mars, Inc.	Focuses on using sustainable materials and promoting closed-loop recycling in packaging.
HP Inc.	Develops packaging using recycled plastics and promotes circularity in its supply chain.

V. Certifications: Certification in packaging is a key tool for informing consumers about the sustainability of the resources used in product production, while also helping industries differentiate their products. Various types of certifications exist, ranging from resource-based to end-product-based. For example, the Forest Stewardship Council [us.fs.org] offers a resource-based certification for packaging materials that use cellulose from forests managed under stringent ecological standards. Products meeting these standards can

display the Forest Stewardship Council logo. Similarly, the USDA Certified Biobased Products program [www.biopreferred.gov] promotes the use of biobased materials and allows certified products to display a special label, making it easier for consumers to identify environmentally friendly options. These certifications are crucial for both producers and consumers in making informed, sustainable choices.

Table 6

## Examples of companies leveraging Certifications

Name of Company	Details of How the Company is Using Certifications
Tetra Pak	Uses Forest Stewardship Council (FSC) certification for its cellulose-based packaging materials.
Mondi	Holds FSC certification and promotes the use of certified sustainable packaging materials across its product lines.
Smurfit Kappa	Achieved FSC certification for its paper-based packaging and focuses on sustainable forest management.
Stora Enso	Uses FSC-certified wood for its packaging solutions, ensuring responsible sourcing of materials.
Amcor	Promotes the use of USDA Certified Biobased Products in its packaging to reduce reliance on fossil fuels.
Nestlé	Utilizes FSC-certified paper in its packaging and is committed to increasing the use of certified sustainable materials.
Unilever	Incorporates both FSC certification and USDA Certified Biobased Products in its packaging portfolio.
PepsiCo	Uses FSC-certified paper and cardboard in its packaging and promotes certified biobased materials.
Danone	Focuses on using USDA Certified Biobased Products and FSC-certified materials in its packaging.
Procter & Gamble	Promotes the use of certified sustainable materials, including FSC-certified paper and USDA biobased products, in its packaging.

#### 4. Conclusion:

Sustainable food packaging is rapidly becoming a critical component of corporate responsibility and environmental stewardship. As consumer awareness of environmental issues grows and regulations become more stringent, companies are increasingly adopting innovative packaging solutions that prioritize sustainability. This research underscores the importance of recycling, the use of sustainable materials, and the integration of design innovations in creating environmentally friendly packaging. The shift towards a circular bioeconomy presents a promising pathway for reducing reliance on non-renewable resources and minimizing waste. Certifications play a vital role in guiding consumer choices and ensuring that products meet rigorous environmental standards. Moving forward, the continued collaboration between industry stakeholders, regulatory bodies, and consumers will be essential in advancing the development and adoption of sustainable packaging practices. The findings of this paper highlight the ongoing efforts and the significant potential for further innovation in the field of sustainable food packaging.

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