Green Nanotechnology: The Key to a Sustainable Future in Cosmetic Packaging?

Renee Lui

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How can green nanotechnology be effectively applied in the development of biodegradable packaging materials for the cosmetics industry to enhance sustainability?

In recent years, companies within the cosmetics industry have grown increasingly focused on sustainability, including the development of environmentally friendly packaging materials. Green nanotechnology offers a promising avenue to address environmental issues, such as plastic packaging waste, by providing innovative solutions for creating biodegradable packaging materials. This paper explores the effective application of green nanotechnology in the development of sustainable packaging materials for the cosmetics industry. It discusses key principles and techniques of green nanotechnology, examines its potential benefits and challenges, and proposes strategies to enhance sustainability through the utilization of biodegradable packaging materials. Integrating green nanotechnology into the cosmetics industry will provide opportunities for sustainable growth within this sector in the future.

Introduction

Robert Swan once stated, "The greatest threat to our planet is the belief that someone else will save it."[1]. Amidst the myriad environmental challenges our planet faces, the cosmetics industry stands at a critical juncture in reevaluating its practices for a sustainable future. Climate change, biodiversity loss, pollution, and resource depletion are among the urgent issues demanding immediate action. Global warming, fueled by greenhouse gas emissions, triggers extreme weather events such as heat waves and hurricanes, while the melting polar ice caps raise sea levels, endangering coastal regions and ecosystems. Concurrently, biodiversity loss, exacerbated by habitat destruction and pollution, threatens the balance of life on Earth. Industrial pollution, plastic waste, and chemical contaminants further imperil ecosystems and human health. Unsustainable consumption patterns and resource exploitation only hasten the depletion of natural resources. Swan's poignant words underscore the responsibility we hold in safeguarding our planet—prompting industries like cosmetics to embrace innovative sustainable solutions.

This statement resonates deeply in the context of the cosmetics industry, where sustainable practices and environmental responsibility are paramount. According to the social justice platform TRVST, beauty products amount to 120 billion trash units each year is generated from packaging alone.[2] Like many others, the cosmetics industry faces the urgent need for sustainable packaging materials to mitigate environmental concerns associated with conventional packaging. The persistence of plastic waste and its detrimental impact on ecosystems have raised alarming environmental concerns. Figure 1 below shows the drastic part packaging plays in landfills.[3] Out of this figure, over 70% of this trash is generated from packaging alone.[2] Like many others, the cosmetics industry faces the urgent need for sustainable packaging materials to mitigate environmental concerns associated with conventional packaging. The persistence of plastic waste and its detrimental impact on ecosystems have raised alarming environmental concerns. Figure 1 below shows the drastic part packaging plays in landfills.

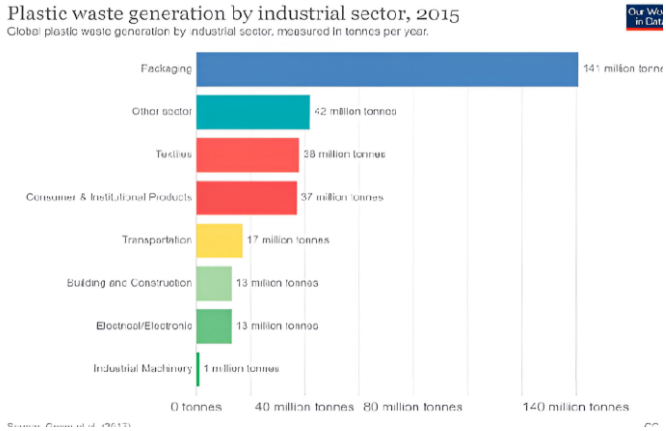

Fig. 1 Plastic waste generation by the industrial sector 2015

Studies have shown the environmental impact of beauty prod-

uct packaging alone has extremely severe implications. Firstly, the generation of plastics and microplastics (MPs) is one of the most serious environmental issues, particularly those associated with the cosmetic industry[4] These plastics can be present in a primary form, that is, as components of the formulations, such as exfoliating agents, or as secondary plastics derived from cosmetic packaging[4]. Microplastics are plastic particles of approximately 5 mm to 0.1 μm.[4]. The fact they are so small, makes it difficult to filter them out in wastewater treatment plants, causing the microplastics to reach water courses and drain into the oceans[4]. Additionally, the microplastics are easily consumed by marine animals, plankton, and other biota, heavily impacting the entire food chain of the marine ecosystem[4]. Moreover, plastics and microplastics are not the only environmentally harmful materials present in cosmetic product packaging. Other substances such as Petroleum derivatives, heavy metals, dyes, surfactants, and detergents need to be safely treated and handled responsibly to avoid harm to the environment, especially potential consequences that result from the disposal of wastewater or other types of waste[4].

Addressing these challenges requires innovative approaches, and green nanotechnology emerges as a promising solution. By effectively applying green nanotechnology in the development of biodegradable packaging materials, the cosmetics industry can enhance its sustainability practices and contribute to a more sustainable future. This research question states, How can green nanotechnology be effectively applied in the development of biodegradable packaging materials for the cosmetics industry to enhance sustainability?" This paper will explore how green nanotechnology can be effectively utilized in the development of biodegradable packaging materials for the cosmetics industry, with a specific focus on enhancing sustainability. Through this research, we will delve into the potential benefits, challenges, and implications of adopting green nanotechnology in the pursuit of sustainable packaging solutions. The cosmetics industry, like many others, grapples with the detrimental impact of plastic packaging on the environment. The excessive use of traditional plastics has led to pollution, waste accumulation, and a pressing need for sustainable alternatives. In recent years, the industry has turned to innovative green technologies to address these challenges effectively. Green nanotechnology, one such cutting-edge field, offers a promising solution for developing eco-friendly packaging materials. By leveraging nanoscale materials and processes, green nanotechnology enables the creation of biodegradable packaging solutions that mitigate the environmental footprint of cosmetic products. These sustainable alternatives not only reduce plastic waste but also align with the industry's growing emphasis on eco-conscious practices.

In addition to green nanotechnology, biopolymer technologies have emerged as another key player in the quest for sustainable packaging within the cosmetics sector[5]. Biopolymers, derived from natural sources such as plants or bacteria, offer a renewable and biodegradable alternative to conventional plastics.[5] . By harnessing the versatility of biopolymers, cosmetic companies can produce packaging materials that are not only environmentally friendly but also exhibit properties like flexibility, durability, and barrier protection, essential for preserving product integrity.

The integration of these sustainable green technologies in the cosmetics industry represents a significant step towards fostering a more sustainable future. By embracing innovation and transitioning to eco-friendly packaging solutions, cosmetic companies can reduce their ecological footprint, meet consumer demand for environmentally conscious products, and contribute to a greener, more resilient planet.

Methodology

The research conducted prior/during the process of writing this paper observed data from the range of years 2010-2024. The specific keywords used to extract data were "green nanotechnology", "sustainable packaging", "polymers", and "cosmetics industry". Over 30 literature reports were reviewed in this process.

The principles of green nanotechnology

To explore the methods in which green nanotechnology can be implemented, the concepts and principles of green nanotechnology need to be understood beforehand. Green nanotechnology refers to the use of nanotechnology to enhance the environmental sustainability of different processes, with nanotechnology being an innovative science that includes the design, characterization, production, and application of structures, devices, and systems by controlling shape and size at the nanometer scale, which covers the size range from 1 nanometer to 100 nanometer[4]. Green nanotechnology is an innovative branch of technology that combines key concepts from green chemistry and green engineering.[6]. It aims to reduce the consumption of energy and fuel where applicable, contributing significantly to lessening environmental impact by conserving raw materials, energy, and water, as well as by reducing greenhouse gasses and hazardous waste[6]. With green nanotechnology, there are 7 key branches where it can be applied: optical engineering, bioengineering, nanobiotechnology, nanofabrication, cosmetics, medicines and drugs, and energy.

Nanotechnology is already an emerging technology that cosmetic companies use in manufacturing their products. Cosmetic manufacturers use nanoscale versions of ingredients as it has many benefits, such as providing better UV protection, and deeper skin penetration, and are suitable for long-term use[4]. This widespread use of nanoscale materials in cosmetics is because these nanoparticles obtain newer properties that differ

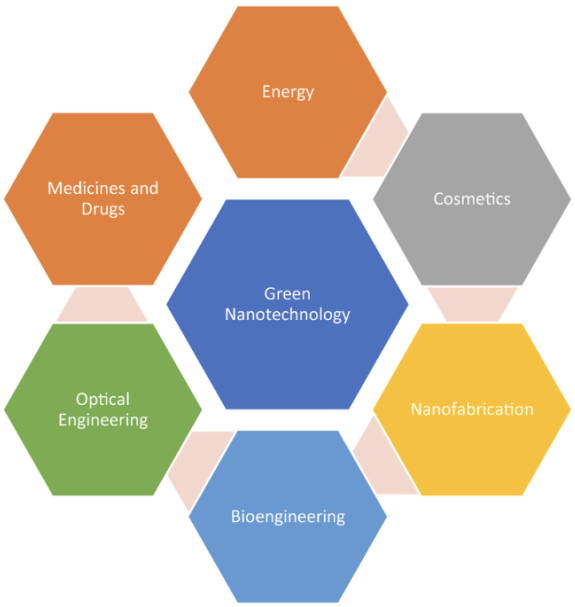

Fig. 2 Branches of nanotechnology applications

from the large-scale particles[4]. The table below displays examples of different types of nanomaterials used in such products.

These altered properties include color, transparency, solubility, and chemical reactivity, making the nanomaterials attractive to the cosmetics and personal care industries. However, with

the products manufactured by different cosmetics companies continually improving, it also means that the demand for the products increases, leading to more and more packing waste being generated. Therefore, it is crucial that companies not only focus on enhancing their products but also lessen the environmental impact caused by their products.

The Cosmetics Industry

The cosmetic industry is a lucrative market with significant financial implications, driven by consumer demand for beauty and personal care products. However, this industry's growth comes with environmental impacts, particularly in terms of packaging waste and carbon footprint. The production and distribution of cosmetics contribute to resource depletion, pollution, and waste generation, highlighting the need for sustainable practices. Market forces play a crucial role in shaping the industry's direction, with increasing pressure from consumers, regulatory bodies, and sustainability advocates pushing companies to adopt eco-friendly solutions and reduce their environmental footprint. Technologies already employed in the cosmetic industry, such as plastic packaging and chemical preservatives, pose challenges for both climate and packaging sustainability. The reliance on non-biodegradable materials contributes to plastic waste accumulation, while the use of synthetic chemicals raises concerns about environmental pollution and health impacts. Addressing these challenges requires a shift towards sustainable approaches that prioritize eco-friendly materials, renewable resources, and innovative packaging solutions. Green nanotechnology emerges as a promising avenue for advancing sustainability in the cosmetic industry, offering biodegradable and environmentally friendly alternatives that can mitigate the environmental impact of traditional cosmetic products and packaging.

Potential Materials For Sustainable Packaging

The packaging for cosmetics products should possess several key features to minimize its environmental impact. Firstly, it should be made from renewable or recycled materials, reducing the reliance on virgin resources and promoting circularity. Secondly, it should be designed for efficient material usage, minimizing waste generation. Additionally, the packaging should be biodegradable or compostable, enabling its decomposition into non-toxic components that can safely return to the environment. Furthermore, it should prioritize lightweight construction to reduce the carbon footprint associated with transportation. Lastly, the packaging should be free from harmful chemicals, ensuring the safety of both consumers and the environment. By incorporating these features, sustainable cosmetics packaging can contribute to the industry's efforts to achieve a more environmentally responsible and socially conscious approach.

Several types of nanomaterials can be utilized in the development of sustainable packaging for cosmetics products. Cellulose is the most abundant natural polymer on Earth, it is derived from natural sources such as wood and plants. It is renewable, nontoxic, and biodegradable. However, it is highly crystalline, degrades before melting, and is very hard to dissolve in common solvents although it is very hydrophilic because of an abundance of hydroxyl groups. Therefore, special attention must be paid to identifying appropriate techniques to produce cellulose nanofibers from solutions and, thus, the conditions under which they should work to control the final morphology[7]. The diagram below gives a visual representation of what a cellulose nanofiber should look like:

Furthermore, CNFs have shown promise in the development of composite materials.

When incorporated into polymer composites, such as bioplastics, CNFs enhance the mechanical strength, impact resistance, and thermal stability of the final product. This makes them suitable for various applications in industries ranging from automotive to construction. In the personal care industry, CNFs act as stabilizers, thickeners, and emulsion stabilizers in the formulation of creams, lotions, and gels[9]. Their presence improves the texture, stability, and sensory attributes of these products.

Table 1 Nanomaterials used in cosmetic products[4]

Nanomaterials	Marketed products	Manufacturer
Zinc oxide and titanium dioxide	Sunforgettable corrector colores SPF 20, sunforgettable SPF 30 brush range, wild to mild skin bronzer.	Colore Science
	Moisturizing dermatone lips 'n' face protection crème	
	Solar defense organic moisturizer	Dermatone
	Olay complete UV protective moisture lotion	Image skincare
	Soltan facial sun defense cream	Proctor and gamble
	Defy: age management exfoliator, EGF complex cocktail, nourish	Boots
Fullerenes and fullersomes	Dr. Brandt new lineless cream	Bellapelle skin studio.
	Revitalizing night cream	Dr. Brandt
	White out/ daily under eye care	MyChelle dermaceuticals LLC
	Zelens fullerene C-60 day cream, zelens fullerene C-60 night cream	
	Coco mademoiselle fresh moisture mist	Sircuit cosmeceuticals
	Calming alcohol-free nanoemulsion	Zelens
	Skin caviar ampoules	Chanel
Nanoemulsions	Pureology COLOURMAX	Chanel precision
	Double dose in a box, laser relief, laser tight	La prairie
	Hydra flash bronzer	Pureology
	Super aqua skin cream range	Dr. Brandt
Nanocapsules	Renutriv range, resilience range	Lancome
	Neutrogena line	
	Revitalift double lifting, revitalift intense lift treatment mask	Enprani
Novasomes	Revlon colorstay stay natural powder, revlon new complexion concealer	Estee lauder
	Leorex hypoallergenic wrinkle nano remover range Renergie microlift eye,	Johnson and johnson
Nanosomes	renergie lift makeup Elixir skin range, pureness matifying compact	L'Oreal
Nano aluminum		Revlon
Nano silicon dioxide		GlobalMed technologies
Lyphazome nanospheres	Moisturizing sunscreen MAX SPF 29, moisturizing sunscreen spf 30	Lancome
		Shiseido
		Dermazone solutions

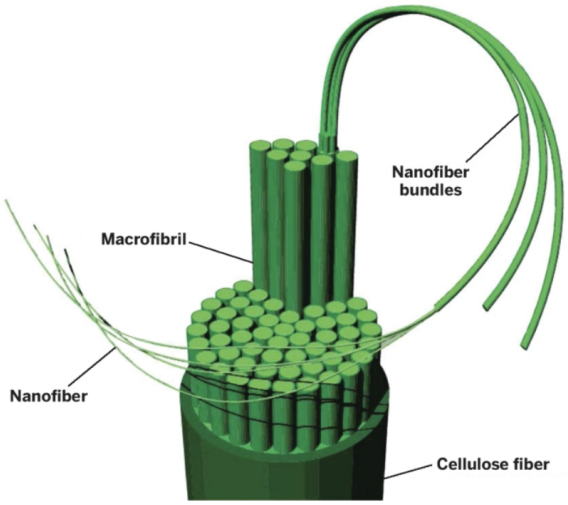

Fig. 3 Diagram of cellulose nanofiber[8]

Additionally, CNFs have applications in water filtration membranes, where their high porosity and filtration efficiency make them ideal for removing contaminants from water sources[9].In the biomedical field, CNFs are being explored for drug delivery systems, wound dressings, and tissue engineering scaffolds due to their biocompatibility and ability to provide structural support[9]. These applications demonstrate the versatility and potential of cellulose nanofibers in contributing to sustainable solutions across various industries.

Another green nanomaterial that can be applied in cosmetic product packaging is silver nanoparticles. Although the main area of application for silver nanoparticles is currently with food packaging, this material possesses many qualities suitable for cosmetic product packaging as well. Silver nanoparticles have previously been prominent in fields such as medicine and biotechnology, as they have strong antimicrobial properties[10]. In food packaging, the role of silver nanoparticles is to keep the food fresh, prolong its shelf life, and prevent bacteria from contaminating it. Below is a diagram of the molecular structure of silver nanoparticles:

Sustainable cosmetics packaging aims to minimize the need for chemical preservatives, which can have negative impacts on the environment and human health. Silver nanoparticles offer a natural and effective alternative to traditional preservatives, as

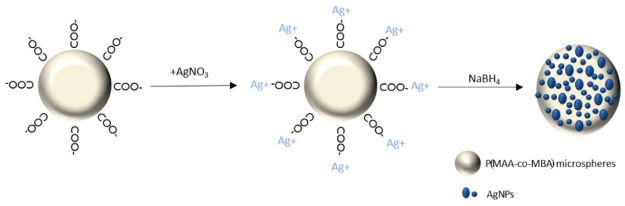

Fig. 4 Diagram of Silver Nanoparticle Molecular Structure (MDPI 2021)

they can help extend the shelf life of cosmetic products without the use of harmful chemicals. By incorporating silver nanoparticles into sustainable packaging materials, cosmetics manufacturers can enhance the product's stability, reduce the risk of contamination, and minimize the need for chemical preservatives. This not only promotes the sustainability of the packaging itself but also contributes to the overall sustainability of the cosmetics industry by reducing its environmental footprint and improving consumer safety.

Clay nanocomposites are another type of nanomaterial derived from natural materials.

Clays are hydrous silicates or aluminum silicates and are fundamentally containing silicon, aluminum or magnesium, oxygen, and hydroxyl with various associated cations[11]. To enhance a material's mechanical strength and barrier properties, clay nanoparticles are combined with/incorporated into other biodegradable polymers[11]. Polymers include polylactic acid (PLA) and polyhydroxyalkanoates (PHA). Polylactic acid is a common biodegradable polymer typically made by extracting the sugars in plants like sugarcane and corn, and polyhydroxyalkanoates are polymers produced by microorganisms[12] Below is a diagram/infographic on how clay particles and biodegradable polymers are incorporated into each other.

In the context of cosmetics packaging, a comparative analysis of cellulose, silver nanoparticles, and clay nanocomposites reveals distinct advantages and considerations. Cellulose, derived from renewable sources, offers biodegradability, non-toxicity, and versatility in applications from stabilizing formulations to enhancing product texture. Its challenges lie in crystallinity and solubility constraints. By contrast, silver nanoparticles, known for antimicrobial properties, provide a natural alternative to chemical preservatives, extending product shelf life sustainably. However, their primary use in food packaging raises questions about direct cosmetic applications. Clay nanocomposites, combining clay nanoparticles with biodegradable polymers, bolster mechanical strength and barrier properties while accelerating biodegradation, thus facilitating composting. The integration of these materials underscores the importance of

selecting eco-friendly options tailored to specific cosmetic packaging needs, with cellulose

excelling in biocompatibility and sustainability, silver

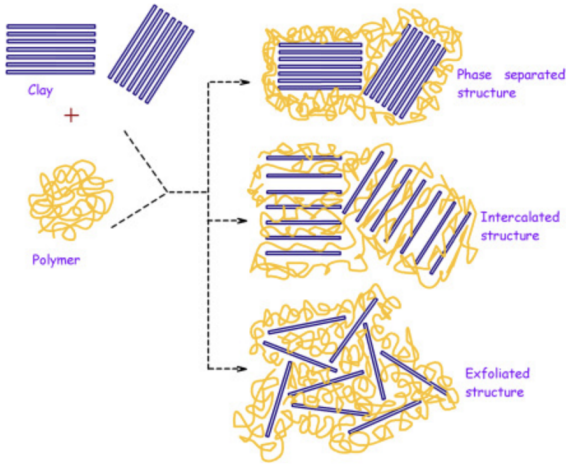

Fig. 5 How clay particles and biodegradable polymers are incorporated into each other[5]

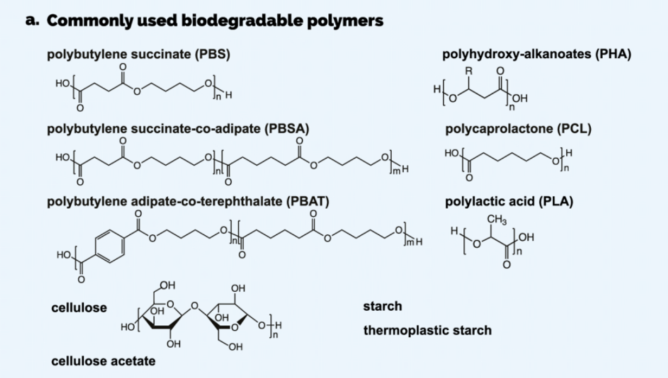

Fig. 6 Common biodegradable polymers[13]

nanoparticles in antimicrobial protection, and clay nanocomposites in structural enhancement and accelerated biodegradation

Fig. 7 The "life cycle" of TheShellWorks product packaging (TheShellWorks)

Difficulties and Issues

Although green nanotechnology has been proven to provide many benefits to the environment, important measures such as cost, the environment in which the materials are produced, and public health and safety must also be taken into consideration. Nanoparticles themselves are not necessarily considered dangerous, however their versatility and their expanded reactivity may pose a threat [14] Additionally, when these threats affect ecosystems and living creatures, it will be deemed as nanopollution [14].

With humans becoming more and more exposed to nanoparticles, the effect they have on human external/internal body systems must be analyzed. There are three entryways for nanoparticles in the human body: the skin, the gastrointestinal tract, and the lungs [14]. If the nanoparticles manage to make it inside the body, there is a high likelihood that nanoparticles will come into contact with immune cells, which can lead to nanoparticle immune system interaction causing inflammation, expanded susceptibility to infectious diseases, or even to immune system diseases or cancer [14]. The goal of green nanotechnology is to enhance the environmental sustainability of different processes. However, the process of creating nanoparticles and using nanotechnology does generate a lot of waste, specifically nanowaste. Nanowaste is known as the gathering of particles that are discharged into the environment or the particles that are discarded when still on their items causing disturbance of the ecosystem [14]. Multiple research studies have shown that nanoparticles are passing through the food chain from smaller to larger organisms [14]. All examined groups of manufactured nanoparticles have been demonstrated to be toxic to aquatic living beings, for example, zebrafish, daphnia, algae, invertebrates, and rainbow trout [14].

Precautionary measures

To limit and control the above hazards, necessary precautions, and measures should be implemented. Firstly, specialists handling or manufacturing nanomaterials should wear personal protective equipment to prevent nanoparticles from entering their bodies. With this, medical screenings should be conducted regularly on those who are consistently exposed to the nanomaterials. Moreover, nanoparticles should be stored and disposed of properly. They can be stored in plastic packs and containers, being labeled clearly. Since all nano waste is potentially hazardous, they should be discarded as synthetic waste.

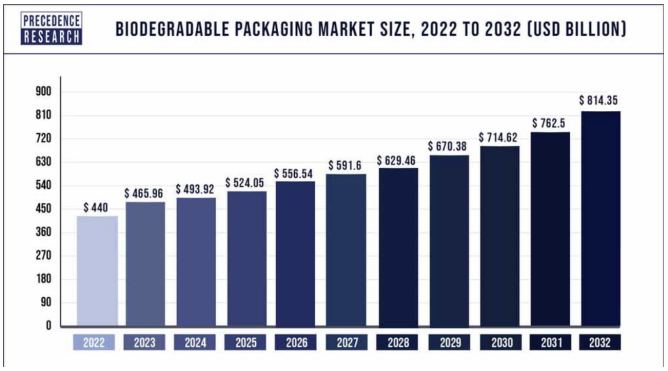

Fig. 8 Estimated biodegradable packaging market size [8]

Current applications in the cosmetics industry

Now that all factors related to green nanotechnology and how they relate to cosmetic packaging have been explored, the current applications of green nanotechnology in the cosmetics industry should be examined. One cosmetic product company called TheShellWorks uses microbes produced by microorganisms to create the packaging for their products. This includes the product containers as well as the outer packaging. It is 100% compostable and biodegradable,proving as a successful application of green nanotechnology in cosmetic packaging, meaning that it is very possible for what has been mentioned above to be implemented globally.

With biodegradable packaging, there are both benefits and challenges. Along with the significantly less harmful environmental impact and reduced carbon footprint, this type of packaging appeals to a wide range of audiences. The current environmental state of the world is in extreme need of saving, so many consumers are actively seeking out eco-friendly products and packaging. Using biodegradable and sustainable packaging can enhance a brand's reputation and appeal to environmentally conscious consumers, leading to increased customer loyalty and market share.

But, there are also multiple disadvantages with the implementation of sustainable packaging. The cost for companies to manufacture biodegradable/environmentally friendly packaging is significantly more expensive than using conventional, unrenewable materials. This is due to the more complex production processes, availability, and economies of scale. Furthermore, some biodegradable materials may have limitations in terms of mechanical strength, barrier properties, or shelf life compared

to traditional non-biodegradable materials. Ensuring that sustainable packaging meets the necessary functional requirements without compromising product integrity can be a challenge for many cosmetic companies.

Despite the progress in green nanotechnology for cosmetics packaging, several research gaps and areas for further investigation remain. One crucial area is the toxicity and safety assessment of nanomaterials used in packaging. This can be monitored by conducting long-term exposure studies and comprehensive risk assessments to ensure the safety of consumers and the environment. Additionally, understanding the potential risks associated with nanomaterials is essential for responsible and sustainable implementation. Assessing the overall environmental impact of different sustainable packaging materials throughout their life cycle is important, as factors such as resource consumption, energy use, and waste generation associated with the production, use, and disposal of the materials must be evaluated to identify the most sustainable options.

The integration of TheShellWorks' sustainable packaging solutions with the principles of green nanotechnology underscores the feasibility of large-scale implementation in the cosmetics industry. While challenges such as production costs and material properties exist, success stories like TheShellWorks highlight the transformative impact of adopting green nanotechnology practices. By addressing technological and economic constraints through innovation, collaboration, and research, the widespread adoption of sustainable packaging solutions in cosmetics can become a reality, offering both environmental benefits and market competitiveness for companies committed to sustainability.

Conclusion

In conclusion, the integration of green nanotechnology into the cosmetics industry holds great promise for achieving sustainability goals, particularly in the realm of packaging materials. By exploring the principles and techniques of green nanotechnology, we can unlock innovative solutions for developing biodegradable and environmentally friendly packaging options. This paper has shed light on the potential benefits and challenges associated with green nanotechnology in the cosmetics industry, emphasizing the importance of considering sustainability in packaging choices. By embracing this approach and implementing strategies to enhance sustainability through biodegradable packaging materials, we can contribute to a more sustainable future for the cosmetics industry and the environment as a whole. The adoption of green nanotechnology represents a significant step towards aligning the industry with the principles of environmental stewardship and advancing towards a more eco-conscious and responsible path.

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