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# Advancements in bio-based materials and low-VOC formulations: Paving the way for sustainable innovation in the coatings industry

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## ABSTRACT

The coatings industry has undergone a significant transformation towards sustainability in response to growing environmental concerns. Traditional coatings, primarily derived from petroleum, contribute to environmental pollution through high VOC emissions and resource-intensive production processes. In contrast, eco-friendly alternatives, including low-VOC, zero-VOC, and bio-based coatings, offer promising solutions by reducing VOC levels and utilizing renewable resources. Notable advancements such as water-based coatings, soy-based alkyd resins, and self-healing technologies highlight the industry's shift towards greener options. Despite the benefits, challenges such as achieving comparable performance to traditional coatings and higher production costs remain. Regulatory frameworks like REACH and the Clean Air Act, along with increased consumer demand for sustainable products, are driving the industry towards these innovative solutions. Future research is expected to focus on enhancing the performance of bio-based and low-VOC coatings, improving recyclability, and developing multifunctional coatings. The continued evolution of the coatings sector towards sustainable practices underscores the importance of reducing environmental impact and fostering responsible innovation.

## KEYWORDS

Sustainable coatings; Low-VOC and zero-VOC coatings; Bio-based materials; Environmental impact

## ARTICLE HISTORY

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## Introduction

In recent years, there has been a notable change in the coatings sector towards eco-friendly and sustainable products. The coatings industry is essential in a range of sectors such as construction, automotive, and manufacturing. Nevertheless, due to growing environmental issues, the sector has been shifting towards more eco-friendly methods and goods. Coatings made from petroleum are a major source of environmental pollution due to the release of VOCs, which damage air quality and add to greenhouse gas emissions. Their manufacturing process also requires a high amount of resource extraction, resulting in habitat depletion and a higher carbon footprint. Switching to environmentally friendly substitutes can help reduce these environmental effects [1]. Materials made from plants and natural resins are being used as alternatives to traditional coatings derived from petroleum. These materials derived from living organisms not only provide better environmental qualities but also offer improved performance attributes, such as enhanced barrier properties, mechanical strength, and self-healing abilities [2].

One of the main environmental issues in the coatings sector has been the utilization of volatile organic compounds (VOCs) because of their environmental and health consequences. These substances are recognized as causing air pollution and posing dangers to human health, such as breathing problems and other negative impacts. In response to these issues, there has been a strong focus on sustainability and creativity in creating low-VOC and VOC-free coatings. Several companies have created formulations with low-VOC and zero-VOC levels [3].

A significant advancement in this field is the creation of water-based coatings. These coatings utilize water as a solvent, rather than organic solvents, which greatly decreases VOC emissions. Water-based coatings not only have eco-friendly qualities but also provide benefits like less smell and simpler cleaning. The progress in polymer technology has allowed these coatings to achieve the same performance attributes as traditional solvent-based coatings, making them a feasible and eco-friendly option [4]. Another new method involves utilizing bio-based materials in coatings. These components come from sustainable sources like plant oils, decreasing reliance on petroleum products and decreasing VOC levels. For instance, sustainable soy-based alkyd resins have been created as a substitute for traditional alkyd resins, offering comparable performance while reducing environmental impact. Furthermore, regulatory frameworks are also pushing the coatings industry towards sustainability alongside these technological advances. Rules like the EU's REACH and US Clean Air Act restrict VOC emissions, pushing companies to create eco-friendly products. The move towards environmentally friendly coatings is motivated not just by regulations but also by a growing consumer desire for sustainable products. Consumers are becoming more conscious of the environmental and health effects of VOCs and are choosing products that are safer and have a smaller impact on the environment. This trend in consumer choice is driving the coatings sector to focus on creating new, environmentally friendly products through research and development efforts [5].

The coatings sector is experiencing a notable shift towards sustainability due to advancements in low-VOC and bio-derived coatings, along with strict regulatory requirements. These advancements not just reduce the negative effects of

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VOCs on the environment and health, but also satisfy the increasing consumer desire for sustainable products. The coatings industry's future hinges on ongoing innovation and dedication to sustainability. Progress has also been made by the sector in creating eco-friendly coatings made from renewable sources. These coatings decrease dependence on petrochemicals and frequently possess a reduced carbon footprint. A few instances are coatings that are created using soybean oil, corn starch, and algae. The increasing recognition of environmental concerns and the desire for eco-friendly packaging from consumers have driven the use of bio-based coatings, especially in the food packaging industry [6,7].

## Green Coating Solutions: The Role of Bio-Based Materials

Coatings made from bio-based materials are sourced from plants, algae, and microorganisms that are renewable biological resources. These resources consist of bio-polymers, bio-resins, and natural oils such as soybean, flaxseed, and castor oil. Cellulose, starch, and chitosan can be used in bio-based coatings, being biodegradable and eco-friendly.

The main benefit of bio-derived materials is their environmentally friendly nature. They decrease reliance on fossil fuels and decrease the carbon footprint of coating products. Furthermore, these substances frequently come with minimal or no VOC emissions, leading to improved indoor air quality and decreased environmental pollution. Bio-based coatings provide distinctive functional characteristics, including improved biodegradability and innate antimicrobial properties, which are advantageous in settings with strict hygiene requirements. Although bio-based materials have advantages, they encounter various obstacles [8]. A major drawback is frequently seen in their inferior performance qualities when compared to synthetic materials, including reduced durability and water resistance. Moreover, the manufacturing of coatings derived from biological sources may incur higher costs because of the increased expense of raw materials and the requirement for specialized processing methods. Challenges also arise concerning the stability and uniformity of bio-based materials, which may differ based on the origin and batch [9].

Recent advancements in bio-derived coatings have been aimed at enhancing their functionality and broadening their usage. One example is the exploration by researchers of using modified starches and cellulose derivatives to improve water resistance and mechanical properties. An important example is the creation of soy-based alkyd resins, which have been effectively utilized in commercial paints to decrease VOC levels and enhance sustainability. These new developments show how bio-based materials have the potential to serve as eco-friendly alternatives to traditional petrochemical coatings in the industry [10].

## Evaluating the Ecological Footprint of Coating Materials

### Traditional coating materials

Conventional coating materials, such as paints, varnishes, and sealants, frequently depend on solvents, resins, and pigments derived from petrochemicals. Some typical instances are alkyd paints, polyurethane coatings, and epoxy resins. These materials are renowned for their strength, protective features, and visual attractiveness. However, they present considerable environmental obstacles. An important issue is the release of volatile organic compounds (VOCs) while applying and curing the product. Volatile organic compounds (VOCs) play a role in causing air pollution by creating ground-level ozone and smog, posing risks to human health and the environment. Furthermore, the manufacture and disposal of conventional coatings frequently incorporate dangerous substances, resulting in pollution of soil and water [11].

### Need for sustainable alternatives

The increasing need for sustainable alternatives is driven by the environmental effects of conventional coatings. Eco-friendly coatings aim to lower environmental impact through decreased VOC emissions, the use of renewable resources, and enhanced biodegradability. The demand for these sustainable options is fueled by the growing regulatory requirements and consumer consciousness of environmental concerns. Rules like REACH in the EU and the Clean Air Act in the US have imposed strict restrictions on VOC levels, prompting manufacturers to create more environmentally friendly products. Additionally, the transition to environmentally friendly coatings is a component of a larger trend towards sustainability in the sector, with the goal of decreasing carbon emissions and encouraging the adoption of renewable materials [12]. An example is bio-based coatings, made from natural oils and resins, are becoming more popular because they have less impact on the environment and lessen reliance on fossil fuels. These substances present a feasible option in place of traditional coatings, delivering comparable performance traits with a focus on eco-friendliness [13].

### Exploring low-VOC and zero-VOC coating technologies

Low-VOC and zero-VOC coatings are new options that aim to decrease the release of volatile organic compounds (VOCs) into the air. Low-VOC coatings have a lower concentration of VOCs compared to regular paints, whereas zero-VOC coatings are made without any measurable VOCs according to regulatory guidelines. These coatings utilize water or other safe solvents for transportation, reducing the release of harmful emissions while being applied and cured. The advantages for the environment of using low-VOC and zero-VOC coatings are considerable. By decreasing VOC emissions, these coatings help enhance air quality and minimize the creation of ground-level ozone, which can lead to respiratory problems and other health issues. Moreover, these coatings frequently have a smaller effect on indoor air quality, making them a more secure option for residential and commercial areas [14].

### Eco-friendly coatings: The benefits of recyclable and reusable solutions

Recyclable and reusable coatings offer a sustainable method for handling coating materials through waste reduction. Recyclable coatings are created to be easily gathered, treated, and reinserted into the production process, diminishing the use of raw materials and lowering landfill waste. These coatings are commonly crafted from recyclable materials like specific polymers and resins. On the flip side, coatings that can be used repeatedly are created to retain their characteristics throughout numerous usage periods. For example, coatings that can be removed and recycled for various uses or surfaces help decrease



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the total amount of coating materials used. This method increases the product's lifespan and decreases its environmental footprint by reducing the need for replacement and disposal. Both recyclable and reusable coatings are essential for driving sustainability in the coatings sector by encouraging circular economy methods and reducing waste [15,16].

### Nanotechnology in coatings

The coatings industry has been transformed by nanotechnology through the use of nanomaterials that improve performance and tackle environmental issues. Nanoparticles like titanium dioxide ($TiO_2$) and zinc oxide (ZnO) are added to coatings to enhance characteristics such as longevity, scratch prevention, and shielding from UV rays. These tiny particles offer a large surface area and reactivity, resulting in improved efficiency using fewer active materials. Moreover, nanotechnology makes it possible to produce eco-friendly coatings with fewer chemical additives and solvents, resulting in low-VOC levels. The improved performance of these coatings often leads to products lasting longer, therefore decreasing the need for frequent application and overall material [17].

### Self-healing coatings

Self-healing coatings offer a new way to increase the longevity of surfaces. These coatings have microcapsules or embedded healing agents that can automatically repair scratches, cracks, or other surface flaws when damaged. When the coating is harmed, it releases healing agents to repair the cracks and restore the protective properties of the coating. This technology greatly decreases the necessity for regular recoating and upkeep, therefore preserving resources and minimizing waste. Self-repairing coatings improve longevity and durability, offering a more sustainable option by reducing the necessity for repairs and replacements [18].

### Smart coatings

Smart coatings possess qualities that adjust to changes in the environment, providing functionality and sustainability. These coatings are capable of altering their color based on temperature, pH, or other factors, enabling the continuous tracking of environmental conditions. Intelligent coatings may also feature self-cleaning surfaces or anti-fogging properties, thus improving their usefulness and longevity. Smart coatings help protect surfaces for longer periods of time, reducing the need for constant upkeep and expanding functionality, thus aiding sustainability by limiting resource usage and prolonging the lifespan of the surfaces they cover [19].

## Practical Examples and Case Study Insights

### Industry examples

Multiple companies have effectively adopted eco-friendly coating materials. PPG Industries has released the "Pitt-Tech®" line of low-VOC coatings, which helps minimize environmental effects and still delivers strong performance in industrial settings. Benjamin Moore provides a well-known illustration with its "Aura®" line, a zero-VOC paint that merges strength with eco-friendliness. Moreover, Sherwin-Williams has created "Harmony®" interior paints that aim to lower VOC emissions and enhance indoor air quality [20].

### Comparative analysis

When traditional coatings are compared to sustainable coatings, the latter typically provide substantial environmental advantages. Conventional coatings frequently have elevated concentrations of VOCs, which add to air pollution and potential health hazards. In comparison, coatings with low-VOC and zero-VOC levels greatly decrease these emissions, enhancing air quality inside and outside. In terms of performance, sustainable coatings that utilize nanotechnology or self-healing abilities can equal or surpass the longevity of conventional coatings. For instance, self-repairing coatings increase the longevity of surfaces by fixing small damages automatically, decreasing the necessity for regular recoating. Despite traditional coatings initially being more durable, sustainable technologies are catching up in performance while reducing environmental impact [21].

## Conquering Challenges and Embracing Chances

### Challenges related to technology

Implementing eco-friendly coatings presents numerous technical obstacles. An important challenge is reaching the same level of performance as traditional coatings, including ensuring longevity, bonding, and protection against environmental elements. Sustainable coatings, especially those containing low-VOC or bio-based ingredients, may not always meet the performance standards of traditional coatings, which can hinder their broad acceptance. Furthermore, the process of creating new technologies frequently involves thorough research and testing to guarantee dependability and uniformity [22].

Costs related to developing and utilizing ecological coatings are one of the economic factors to be taken into account. The cost of raw materials for environmentally friendly coatings may be higher, and specialized equipment may be needed for the manufacturing processes. Nonetheless, regulations like REACH in the European Union and the Clean Air Act in the U.S. set tighter restrictions on VOC emissions, pushing the sector towards more environmentally friendly options and offering financial rewards for adherence [23].

### Opportunities for innovation

Electrophoretic deposition (EPD) is a technique used to deposit particlesSignificant possibilities exist for creativity in eco-friendly coatings. Progress in nanotechnology, self-repairing coatings, and intelligent coatings can improve functionality while decreasing environmental harm. Additional investigation on bio-derived materials and recycling techniques may result in increased sustainable manufacturing methods and solutions for disposal. Exploring these regions can lead to substantial advancements in developing eco-friendly and efficient coating solutions [24].

## Exploring Future Prospects

### Research and innovation

In the future, sustainable coatings research is expected to emphasize multiple important areas. Improving bio-based and low-VOC coatings' performance to meet or surpass that of traditional coatings is crucial. Advancements in material science, like high-tech bio-resins and improved nanomaterials, are required to tackle existing performance deficiencies. Furthermore, it will be essential to enhance the recyclability of coatings and create more cost-effective production methods to increase overall use. Exploration of multifunctional coatings that integrate self-cleaning, self-healing, and intelligent responsiveness features may provide valuable advantages as well [25].



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## Trends in the business sector

There is anticipation that the coatings industry will keep progressing towards increased sustainability and responsible innovation. It is expected that there will be a stronger focus on minimizing environmental effects due to more stringent regulations and a higher demand from consumers for sustainable products. The rise of circular economy principles, where coatings are made for reuse and recycling, will increase in popularity in the future. Moreover, advancements in technology such as digitalization and smart coatings will contribute to enhancing innovation and efficiency within the industry. Companies will invest more in research and development to achieve sustainability goals, while also ensuring their products maintain high performance and functionality [26].

## Conclusions

This brief overview has examined different aspects of eco-friendly coatings, such as advanced technologies and how they affect the environment. We talked about various bio-based materials like soy-based alkyd resins and waterborne coatings, which help the environment by decreasing the use of fossil fuels and reducing VOC emissions. We also emphasized progress such as nanotechnology, self-repairing, and intelligent coatings that boost efficiency while reducing harm to the environment. Furthermore, the efficiency of sustainable coatings in decreasing pollution was highlighted through industry examples and comparative analyses when compared to traditional products. Issues like technical performance and economic expenses were highlighted, as well as possibilities for more innovation and research.

The significance of sustainable coatings is in their ability to greatly lower the carbon footprint of the coatings sector. The industry can reduce environmental damage and support a sustainable future by using eco-friendly materials and advanced technologies. Advancements in coatings enhance performance as well as promote responsible resource utilization and waste minimization. With stricter regulations and growing consumer interest in eco-friendly products, ongoing investment in research and development will be crucial in promoting responsible innovation and meeting sustainability objectives in the long run. Embracing these developments will contribute to the coatings industry moving towards improved environmental responsibility and effectiveness.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## References

1. Adeboye SA, Adebowale AD, Siyanbola TO, Ajanaku KO. Coatings and the environment: a review of problems, progress and prospects. IOP Conf Ser Earth Environ Sci. 2023;(1):012012. https://doi.org/10.1088/1755-1315/1197/1/012012
2. Faccini M, Bautista L, Soldi L, Escobar AM, Altavilla M, Calvet M, et al. Environmentally friendly anticorrosive polymeric coatings. Appl Sci. 2021;11(8):3446. https://doi.org/10.3390/app11083446
3. Jiménez-López AM, Hincapié-Llanos GA. Identification of factors affecting the reduction of VOC emissions in the paint industry: Systematic literature review-SLR. Prog Org Coat. 2022;170:106945. https://doi.org/10.1016/j.porgcoat.2022.106945
4. Chek YW, Ang DT. Progress of bio-based coatings in waterborne system: Synthesis routes and monomers from renewable resources. Prog Org Coat. 2024;188:108190. https://doi.org/10.1016/j.porgcoat.2023.108190
5. Mucci VL, Aranguren MI, Amalvy JI, Hormaiztegui ME. Recent developments in waterborne polyurethanes for coating applications. Eco-Friendly Waterborne Polyurethanes. 2022: 253-266. https://doi.org/10.1201/9781003173526
6. Thomas D, Philip E, Sindhu R, Ulaeto SB, Pugazhendhi A, Awasthi MK. Developments in smart organic coatings for anticorrosion applications: a review. Biomass Conv Bioref. 2022;12(10): 4683-4699. https://doi.org/10.1007/s13399-022-02363-x
7. Gadhave RV, Gadhave CR, Dhawale PV. Plastic-free bioactive paper coatings, way to next-generation sustainable paper packaging application: A review. Green Sustain Chem. 2022;12(2):9-27. https://doi.org/10.4236/gsc.2022.122002
8. Kaushal N, Singh AK. Advancement in utilization of bio-based materials including cellulose, lignin, chitosan for bio-inspired surface coatings with special wetting behavior: A review on fabrication and applications. Int J Biol Macromol. 2023:125709. https://doi.org/10.1016/j.ijbiomac.2023.125709
9. Cloutier M, Mantovani D, Rosei F. Antibacterial coatings: challenges, perspectives, and opportunities. Trends Biotechnol. 2015;33(11):637-652. https://doi.org/10.1016/j.tibtech.2015.09.002
10. Rastogi VK, Samyn P. Bio-based coatings for paper applications. Coatings. 2015;5(4):887-930. https://doi.org/10.3390/coatings5040887
11. Sarcinella A, Frigione M. Sustainable and bio-based coatings as actual or potential treatments to protect and preserve concrete. Coatings. 2022;13(1):44. https://doi.org/10.3390/coatings13010044
12. Cunningham MF, Campbell JD, Fu Z, Bohling J, Leroux JG, Mabee W, et al. Future green chemistry and sustainability needs in polymeric coatings. Green Chem. 2019;21(18):4919-4926. https://doi.org/10.1039/C9GC02462J
13. Jouyandeh M, Seidi F, Habibzadeh S, Hasanin MS, Wiśniewska P, Rabiee N, et al. An overview of green and sustainable polymeric coatings. Surf Innov. 2023;12(5-6):268-281. https://doi.org/10.1680/jsuin.23.00043
14. Liu Y, Zeng C, Wang M, Shao X, Yao Y, Wang G, et al. Characteristics and environmental and health impacts of volatile organic compounds in furniture manufacturing with different coating types in the Pearl River Delta. J Clean Prod. 2023;397: 136599. https://doi.org/10.1016/j.jclepro.2023.136599
15. Cherrington R, Marshall J, Alexander AT, Goodship V. Exploring the circular economy through coatings in transport. Sustain Prod Consum.2022;32:136-146. https://doi.org/10.1016/j.spc.2022.04.016
16. Sfameni S, Rando G, Plutino MR. Sustainable secondary-raw materials, natural substances and eco-friendly nanomaterial-based approaches for improved surface performances: an overview of what they are and how they work. Int J Mol Sci. 2023;24(6):5472. https://doi.org/10.3390/ijms24065472
17. Vidales-Herrera J, López I. Nanomaterials in coatings: An industrial point of view. InHandbook Nano Manu Appl. 2020; 51-77. https://doi.org/10.1016/B978-0-12-821381-0.00003-X
18. Mirabedini SM, Alizadegan F. Self-healing polymeric coatings containing microcapsules filled with active materials. InSelf-Heal Poly Syst. 2020;235-258. https://doi.org/10.1016/B978-0-12-818450-9.00009-X
19. Cole IS. Smart coatings for corrosion protection: an overview. Handbook of Smart Coatings for Materials Protection. 2014;29-55. https://doi.org/10.1533/9780857096883.1.29
20. Christ U. High performance–low VOC-content: innovative and trend-setting coating systems for industrial applications. Macromol Symp. 2002;(187):759-770 https://doi.org/10.1002/1521-3900(200209)187:1%3C759::AID-MASY759%3E3.0.CO;2-E
21. Sandhu HS, Goyal D, Sharma A, Goyal T, Jarial S, Sharda A. Sustainable development in cold gas dynamic spray coating process for biomedical applications: Challenges and future perspective review. Int J Interact Des Manuf. 2023:1-7. https://doi.org/10.1007/s12008-023-01474-7



https://doi.org/10.61577/jcti.2024.1000010

22. Calovi M, Zanardi A, Rossi S. Recent advances in bio-based wood protective systems: a comprehensive review. Appl Sci. 2024;14(2):736. https://doi.org/10.3390/app14020736
23. Bayer IS. Superhydrophobic coatings from ecofriendly materials and processes: a review. Adv Mater Interfaces. 2020;7(13):2000095. https://doi.org/10.1002/admi.202000095
24. Zhu Q, Chua MH, Ong PJ, Lee JJ, Chin KL, Wang S, et al. Recent advances in nanotechnology-based functional coatings for the built environment. Mater Today Adv. 2022;15:100270. https://doi.org/10.1016/j.mtadv.2022.100270
25. Ghobakhloo M, Iranmanesh M, Grybauskas A, Vilkas M, Petraitė M. Industry 4.0, innovation, and sustainable development: A systematic review and a roadmap to sustainable innovation. Bus Strategy Environ. 2021;30(8):4237-4257. https://doi.org/10.1002/bse.2867
26. Parida V, Sjödin D, Reim W. Reviewing literature on digitalization, business model innovation, and sustainable industry: Past achievements and future promises. Sustainability. 2019;11(2):391. https://doi.org/10.3390/su11020391



https://doi.org/10.61577/jcti.2024.1000010