International Journal of
Science, Architecture, Technology and Environment

Green Chemistry and Sustainable Development

Dr. Rahul Arya[1*], Nitya[2], Meenu Kumari[2], Pooja Devi[2]

[1]*Associate Professor , Department of Chemistry, Shri Ram College, Muzaffarnagar(U.P), India*

[2]*Students of M.Sc IV Semester Chemistry, Department of Chemistry, Shri Ram College, Muzaffarnagar(U.P), India*

[*]*Corresponding author*

DOI: https://doi.org/10.63680/hn76tgf323vfgf

Abstract

The quickly developing area of "green chemistry" aims to create chemical products and procedures that reduce or completely do away with the usage and production of dangerous materials. The pursuit of sustainability in the face of resource depletion and environmental issues has prompted a paradigm shift in the discipline of chemistry. This study looks at the important roles that sustainable materials and green chemistry play in creating eco-friendly solutions. Green chemistry allows us to rethink chemical reactions and material production to reduce their detrimental effects on human health and ecosystems. Its tenets are environmental responsibility, efficiency, and safety. Because of this, sustainable materials are now a crucial component of sustainable development, serving as the cornerstone for a more environmentally sensitive future.Utilizing nature's richness and wisdom to inform the creation of new, environmentally friendly materials, biomimicry and renewable resources are analyzed as key strategies in sustainable material design. The study also discusses the methods and tools used to evaluate and compare the environmental footprints of sustainable and conventional materials, as well as the assessment of the environmental impact of sustainable materials. This study emphasizes the critical role that green chemistry ideas play in building a more sustainable and ecologically friendly future by combining sustainable material creation with green chemistry principles.The study also highlights the significance of green chemistry and sustainable materials in developing creative, environmentally responsible solutions. Through the integration of knowledge, creativity, and ethical stewardship, these interrelated professions offer a viable path towards a more sustainable and ecologically conscious world.

Keywords: Green chemistry; Sustainable chemistry; Environmental impact; Pollution prevention; Resource conservation; Green solvents; Biomimicry

Introduction

In a time when environmental concerns are growing and there is a growing worldwide commitment to sustainable practices, the combination of science and innovation provides a ray of hope. At the heart of this confluence lies the discipline of Green Chemistry, a paradigm changes in thinking and practice that seeks to establish a more harmonious relationship between human activity and the world we live on. One of the main focuses of this broad discipline is the development of sustainable materials, or materials created and manufactured with a deliberate commitment to resource efficiency, environmental friendliness, and minimal environmental effect.

The urgency of addressing resource depletion, environmental degradation, and the adverse effects of conventional industrial methods cannot be overstated. Society is currently facing an unparalleled sustainability dilemma as a result of pollution, greenhouse gas emissions, and the relentless consumption of finite resources. Green chemistry, a set of concepts and techniques that drive the development of sustainable materials and processes, consequently, becomes a significant intellectual force. This essay seeks to examine the intricate connection between sustainable materials and green chemistry, offering a comprehensive examination of how these two domains collaborate to provide ecologically acceptable solutions for the contemporary world. It is proof that we all have a responsibility to preserve the planet and its resources for future generations.

This study aims to uncover the revolutionary potential of these interconnected domains by closely examining the fundamentals of green chemistry, the properties of sustainable materials, and creative manufacturing methods. We will look into how sustainable materials can be created, manufactured, and applied in a range of industries, such as electronics and construction, to reduce environmental effects and hasten the transition to a more sustainable future.

This research will also examine case studies of companies and projects that are at the forefront of sustainable materials innovation, showcasing their achievements and challenges overcome. By doing this, we want to inspire further research, innovation, and action in the quest for a more environmentally friendly and sustainable world.

In essence, "Sustainable Materials and Green Chemistry: Pioneering Eco-Friendly Solutions" explores the incredible potential that arises when science and sustainability are combined, demonstrating how these domains can offer practical answers to some of the most urgent environmental issues of our day. "Green chemistry," sometimes known as "sustainable chemistry," aims to minimize or completely do away with the use of dangerous substances in the creation, production, and usage of chemical products. The primary goals of green chemistry are to maintain the effectiveness of chemical processes and products while minimizing their detrimental consequences on the environment and human health. Paul Anastas and John Warner first proposed these concepts in the 1990s, and they have since grown to become fundamental guidelines for scientists and chemists working to build a more sustainable future. The following are the twelve green chemistry principles:

Prevention: It is better to stop pollution and waste before it starts than to clean it up after it has already been created. This idea promotes the creation of goods and procedures that produce the least amount of waste and harm the environment as little as possible.

Atom Economy: Reduce the number of byproducts produced by a chemical process by maximizing the integration of all utilized components into the finished product.

Reduced Hazardous Chemical Synthesis: Develop synthetic procedures that produce and employ materials that are minimally hazardous to the environment or human health.

Creating Safer Chemicals: Create chemicals that are equally effective as traditional ones but less harmful. This idea aims to minimize the risk of damage while maintaining functioning.

Safer Solvents and Auxiliary Materials: Choose solvents and auxiliary materials that are less harmful to the environment.

Design for Energy Efficiency: Reduce greenhouse gas emissions and energy consumption by optimizing energy utilization in chemical manufacturing.

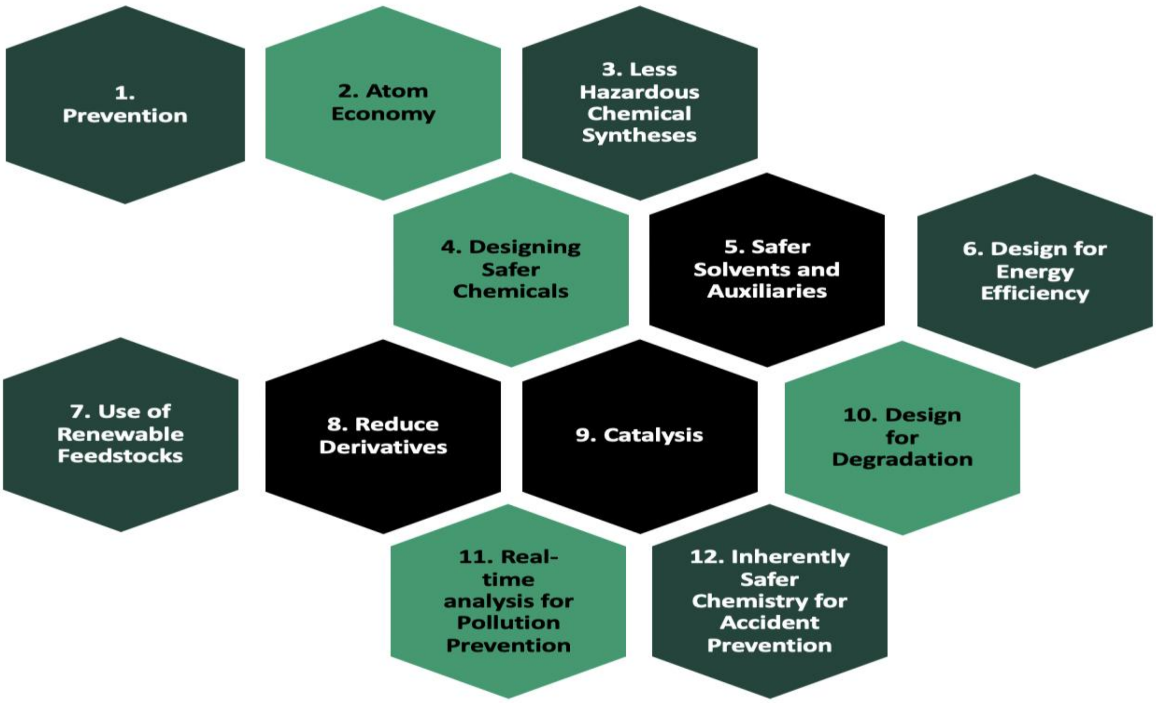
Use of Renewable Feedstocks: Utilize renewable raw materials, such as biomass or agricultural products, to reduce reliance on non-renewable resources.

Reduce Derivatives: Reduce blocking and group protection, which are frequently necessary in conventional chemical processes but lead to extra waste. Chemical reactions can be made more efficient with the use of catalysts, consuming less energy and resources and generating less waste.

Design for Degradation: Make sure an object decomposes into non-toxic elements after usage to lessen its environmental persistence.

Real-Time Analysis to Stop Pollution: Develop methods for within-process management and monitoring to improve processes and stop the production of hazardous compounds.

Safer Chemistry by Nature to Prevent Accidents: Develop materials and procedures that are inherently less hazardous to lower hazards to workers and the public.The world becomes cleaner and better as a result of these suggestions, which help companies, scientists, and chemists make more ecologically responsible decisions in their job. Innovative, environmentally friendly products and processes that benefit society while posing the least amount of harm to the environment can be developed via the use of green chemistry concepts.



https://openbooks.lib.msu.edu/app/uploads/sites/116/2024/03/Figure-1.pngECO-FRIENDLY SUPPLIES

Sustainable resources must be used in green chemistry. The goal of green chemistry is to create chemical processes and products that are less harmful to the environment and produce less waste. Sustainable materials are crucial to achieving these objectives because they serve as the basis for creating greener procedures and goods. These are a few examples of environmentally friendly compounds that are commonly used in green chemistry.

Renewable Resources: Materials derived from renewable resources, such as plant-based feedstocks (like biomass and cellulose), agricultural waste, and bio-based polymers (like PLA and PHA), can serve as sustainable alternatives to conventional petroleum-based materials. They reduce our reliance on fossil fuels and can be produced with less environmental impact.

Recycled Materials: Reducing the environmental effect of industrial processes can be achieved by recycling materials like paper, glass, and certain plastics. Incorporating recycled materials into new products reduces waste and conserves resources.

Green Solvents: In many different chemical reactions, solvents are essential. Green solvents are environmentally benign, non-flammable, and non-toxic. Examples that can often replace traditional organic solvents that are hazardous to human health and the environment include water, ionic liquids, and supercritical fluids.

Biodegradable Polymers: Polylactic acid (PLA) and polyhydroxyalkanoates (PHA) are two eco-friendly alternatives to conventional plastics. They can break down into non-toxic chemicals under normal conditions, reducing the pollution that plastic causes.

Nanoparticles: Environmentally conscious designed nanoparticles can be used in green chemical applications. For instance, nano catalysts can reduce the demand for high-temperature and high-pressure settings by improving reaction efficiency.

Natural Extracts: In a number of industries, including medicine, cosmetics, and agriculture, essential oils, bioactive compounds, and plant extracts can be used as environmentally friendly alternatives to manufactured chemicals. Porous materials known as Metal-Organic Frameworks (MOFs) are used in gas storage, separation, and catalysis. In green chemistry, they might be employed to absorb and change greenhouse gasses and other contaminants.

Natural Fibers: Textile and composite industries can reduce their adverse environmental consequences by using sustainable fibers like jute, hemp, and bamboo in place of conventional materials.

Cellulose-Based Materials: Cellulose and its derivatives can be used to create sustainable films, coatings, and packaging materials that have the advantages of biodegradability and renewability. The use of nanotechnology principles with a focus on sustainability is known as "green nanotechnology."Examples of this include the use of non-toxic nonmaterial’s or nanoparticles for water purification and pollution removal. Green chemistry techniques have the potential to provide products and processes that are less wasteful and harmful to the environment.

Manufacturing and Synthesis in an Ecological Way

The term "Eco-Friendly Synthesis and Manufacturing" describes the creation and use of environmentally responsible and sustainable processes for the production of goods, chemicals, and materials. This approach aims to reduce resource consumption, waste generation, toxic emissions, and the adverse environmental effects of manufacturing operations. The following are essential components of ecologically friendly synthesis and manufacturing:

Principles of Green Chemistry: Green chemistry offers guidelines for environmentally responsible manufacture and synthesis. The design of processes that are intrinsically safer, generate less waste, employ safer chemicals, and consume less energy and resources is the focus of these concepts.

Decreased trash Generation: One of the primary objectives is to lessen the quantity of trash generated during manufacturing. Cleaner production methods, material recycling and reuse, and effective process design can all help achieve this.

Energy Efficiency: Eco-friendly manufacturing seeks to reduce energy consumption through process optimization, the use of renewable energy sources, and the use of energy-efficient equipment.

Safer Chemicals: Safer alternatives are investigated and fewer hazardous or toxic chemicals are employed. This reduces the likelihood of accidents, exposure to hazardous substances, and environmental damage.

Resource Efficiency: Optimizing the utilization of existing resources is the aim of sustainable production. This means using sustainable feedstocks, recycling materials, and minimizing the use of rare or scarce resources.

Biocatalysts and Enzyme Engineering: Eco-friendly synthesis commonly uses biocatalysts, such as enzymes, to carry out chemical reactions with high selectivity and minimal waste. Enzyme engineering can be used to optimize biocatalysts for specific processes.

Cleaner Technologies: Industrial operations can have less of an adverse environmental impact by utilizing greener technologies such as membrane separation, microwave heating, and supercritical fluid extraction.

Life Cycle Assessment (LCA): LCA assesses how a process or product affects the environment from the time raw materials are extracted to the point of disposal. It helps identify areas that require improvement and guides decision-making.

Process Intensification: Often a part of eco-friendly manufacturing, process intensification involves increasing production rates and product yields while using fewer resources and creating less waste.

Innovative Materials: The development of eco-friendly materials such biodegradable polymers, sustainable composites, and eco-friendly coatings makes it possible to use more ecologically friendly production techniques.The circular economy's guiding principles include creating goods and procedures with a focus on recycling, remanufacturing, and reuse in order to minimize waste and resource depletion.

Regulatory Compliance: Manufacturers are required to follow environmental regulations and standards in order to ensure that their activities are both safe and environmentally responsible. Environmentally friendly synthesis and manufacture are essential for addressing environmental challenges, reducing industry carbon footprints, and promoting a more sustainable and circular economy. Businesses can lower their environmental footprint, increase operational efficiency, and ultimately save money by using these strategies.

Utilizing renewable resources and biomimicry

Biomimicry and renewable resources are two key tactics in green chemistry and sustainable technology that leverage natural inspiration and replenishable materials to develop environmentally favorable solutions. Below is a summary of each concept and how it relates to the others:

Renewable Resources

Renewable resources are natural materials or energy sources that can be constantly restored in a short period of time, usually on a human timeline. Because they lessen our dependency on limited, non-renewable resources like minerals and fossil fuels, these resources are crucial for sustainable development. Among the renewable resources are, for instance:

Biomass: Plant-based resources such as wood, agricultural waste, and algae can be used to create energy, biofuels, and naturally decompose chemicals and polymers.

Solar Energy: Because solar power plants generate electricity using solar radiation, they are sustainable and clean power sources.

Wind Energy: Wind turbines provide a renewable substitute for fossil fuel-based power generation by using the kinetic energy of the wind to create electricity. Using the energy of moving water, like that found in rivers and dams, to generate electricity is known as hydropower.

Geothermal Energy: Heat from the Earth's interior can be used to heat buildings and generate energy.

Tidal and Wave Energy: The energy of ocean tides and waves can be captured and converted into electrical power. Utilizing renewable resources improves the environment, reduces greenhouse gas emissions, and stops the depletion of natural resources, all of which contributes to a more sustainable future.

Biomimicry: The technique of enhancing technology and resolving human issues by drawing inspiration from nature is also referred to as biomimetics or nature-inspired design. Biomimicry is the study and modeling of biological systems, structures, processes, and strategies to create more sustainable and efficient products and processes. Here are a few examples of biomimetic applications:

Resources: Making strong, lightweight materials by modeling them after the structure of bones, shells, or spider silk

Energy Production: Building wind turbines that mimic the efficiency of plant photosynthesis by using solar panels or bird wing aerodynamics.

Medicine: Developing drug delivery systems and medical devices based on organic materials from living organisms and the body's inherent functions. Biomimicry often results in highly efficient technologies that are well adapted to their intended applications, as well as more sustainable and ecologically friendly solutions. It promotes sustainable behaviors and increases awareness of the natural world by fusing human technology with nature's tried-and-true remedies.The combination of biomimicry and renewable resources refers to the use of naturally occurring renewable materials as models for environmentally friendly product design and production techniques. By combining the benefits of renewable resources with the inventive designs found in nature, this approach seeks to create a more sustainable and harmonious relationship between human technology and the environment.

Assessing the environmental impacts

Environmental Impact Assessment (EIA), which evaluates the potential environmental consequences of chemical processes, products, or innovations over their whole life cycle, is a crucial component of green chemistry. This assessment promotes environmentally responsible behavior while aiding in the detection and reduction of adverse impacts. The primary aspects of EIA in connection with green chemistry are as follows:

Life Cycle Assessment (LCA) is a comprehensive method for evaluating the environmental impact of a process or product from inception to decomposition. It considers all stages, such as raw material extraction, manufacturing, usage, and disposal. Performing life cycle assessments (LCAs) to accurately quantify environmental implications is a key component of green chemistry.

Hazard Assessment: An EIA assesses the risks and toxicity of using particular chemicals in a process in green chemistry. By highlighting possible threats to the environment and public health, this evaluation helps choose safer choices.

Chemical Risk Assessment: When assessing the potential dangers that chemicals offer, factors such as persistence, bioaccumulation, and toxicity (PBT) and endocrine-disrupting properties are taken into consideration. Reducing the usage of compounds with high PBT or endocrine-disrupting potential is the goal of green chemistry.

Energy and Resource Efficiency: EIA examines the amount of energy and resources utilized in chemical reactions. This study identifies opportunities to improve energy efficiency, reduce greenhouse gas emissions, and promote resource efficiency.

Waste Reduction: One of the main tenets of green chemistry is the reduction of waste output. EIA examines waste streams, investigates methods for waste reduction, recycling, and reuse, and evaluates the environmental impact of trash disposal. The goal of green chemistry is to lessen the amount of hazardous contaminants and byproducts that are produced during chemical processes. EIA is used to identify and quantify the presence of such compounds and their potential environmental impact.

Environmental Impact Indicators: To measure and evaluate the specific environmental impacts of chemical processes and products, the Environmental Protection Agency (EIA) uses a range of indicators, including carbon footprint, ecotoxicity, and water footprint. the specific effects that chemical reactions and products have on the environment.

Alternative Assessments: In order to identify alternatives that have a lower environmental impact, EIAs assess different products or processes. This could mean comparing different materials or chemical production techniques to see which is the most eco-friendly.

Compliance with laws: Green chemistry considers environmental norms and laws as part of the EIA. This guarantees that meeting or exceeding regulatory criteria is one of the primary goals of chemical processes.

Openness and Stakeholder participation: In green chemistry, EIA frequently entails stakeholder participation and openness in reporting. Working with a range of stakeholders, including industrial partners, community organizations, and regulatory agencies, can lead to more informed decision-making.

Continual Improvement: Rather than being a one-time event, EIA is a continual process. Green chemistry practitioners continuously assess and improve processes and final products to reduce their long-term environmental impact. By conducting thorough EIAs, green chemistry practices can effectively detect, assess, and mitigate any environmental hazards and impacts associated with chemical processes and products. This proactive approach guarantees that discoveries in green chemistry are in line with sustainability objectives and help create a more sustainable and ecologically conscious future.

TROUBLES AND DIFFICULTIES

Although there are many obstacles that must be overcome before green chemistry can be successfully applied on a wide basis, it holds great promise for reducing the damage that chemical processes and products inflict to the environment and human health. Some of the primary challenges and barriers in the subject of green chemistry include the following:

Cost considerations: Initially, developing and implementing green chemistry technologies and procedures may be more expensive than employing traditional methods. This might deter businesses from adopting eco-friendly procedures, especially if they prioritize quick cost savings.

Lack of Knowledge: Many industries and individuals do not fully comprehend the principles and benefits of green chemistry. Stakeholders must be educated and made aware of the importance of sustainability if chemistry is to be used more broadly.

Regulatory Barriers: Green chemistry principles may not always be supported by the rules and regulations in place. Navigating complex regulatory regimes can be challenging, and it can be required to advocate for legislative reforms that favor green chemistry practices.

Risk Aversion: Industries may be hesitant to adopt innovative, cutting-edge methods due to the potential dangers and uncertainties associated with green chemical processes and materials. Demonstrating the reliability and safety of green alternatives is essential.

Lack of Investment: Funding for the study and creation of green chemistry solutions is usually insufficient. Accelerated development of ecologically friendly materials and processes is required, necessitating more financing and resources.

Opposition to Change: Opposition to change can be a significant barrier in well-established sectors. Making the transition from conventional to green chemical methods may require cultural and mental changes.

Challenges with Scale-Up: When green chemistry inventions are scaled up for industrial production, they may encounter difficulties even if they are successful at modest scales. Ensuring that green operations are both lucrative and scalable is challenging.

Complexity and Technical Challenges: Some green chemistry solutions are technically complex and may require specialized skills and equipment. Overcoming technical challenges and making green methods accessible to a larger audience are imperative.

Restricted Supply of Green Alternatives: In some circumstances, there may be a limited supply of green alternatives, such as particular sustainable materials or solvents. For these alternatives to be widely used, their availability must be increased.

Education and Training: More education and training programs are required to give the next generation of chemists and engineers the skills they need to successfully implement green chemistry techniques.

International Cooperation: In order to solve environmental issues, international cooperation and standardization are usually required. More broadly, the development of green chemistry may be hampered by a lack of international coordination. Notwithstanding these challenges, innovative solutions and heightened awareness of the need for sustainable practices are driving the continued development of green chemistry. To overcome these obstacles, governments, industry, academia, and civil society must collaborate to prioritize and advance the implementation of green chemistry principles and practices.

Future prospects and innovations

Green chemistry has enormous potential for the future and is essential to resolving environmental and sustainability issues worldwide. The continuous development of green chemistry is being propelled by the development of innovative solutions and a growing understanding of the necessity of sustainable practices. Some key areas for innovation in green chemistry and its possibilities are as follows:

Cutting-Edge Sustainable Materials: Green chemistry will be crucial to the creation of cutting-edge sustainable materials such as high-performance biopolymers, biodegradable plastics, and novel composite materials. By replacing traditional, petroleum-based materials, these materials will contribute to waste reduction.

Green Synthesis and Catalysis: Advances in catalysis, including the use of enzymes, catalysts, and novel reaction mechanisms, will lead to more efficient and ecologically friendly chemical processes. Greener synthetic pathways will be developed in order to lower waste and energy use.

Integration with the Circular Economy: The principles of the circular economy, which place an emphasis on designing items for recycling, remanufacturing, and reuse, will be in line with green chemistry. This approach will promote resource efficiency and reduce waste. By combining smart materials, nanotechnology, and green chemistry principles, responsive materials and sensors that can identify and respond to changes in the environment will be developed. This will make a variety of applications more sustainable.

Clean Energy Solutions: Green chemistry will contribute to the development of cleaner, more sustainable energy technologies such as better batteries, fuel cells, and photovoltaics. These technologies will reduce greenhouse gas emissions and dependency on fossil fuels.

Waste Valorization: Green chemistry will continue to seek for new methods to convert waste streams and contaminants into valuable goods such as chemicals, fuels, and materials in order to reduce environmental pollution.

Sustainable Agriculture: Green chemistry principles will be applied to develop safer and more effective fertilizers, agrochemicals, and pest control methods in order to support ecologically friendly and sustainable agriculture. Advances in biotechnology and synthetic biology will make it possible to produce microbes for the more efficient and sustainable manufacturing of drugs, biofuels, and other materials.

Education and Training: The field's educational programs and training will expand in order to give a new generation of scientists, engineers, and professionals the skills they need to lead green chemistry breakthroughs.

Global Cooperation: The adoption of green chemistry techniques and the creation of solutions for transboundary environmental problems will be facilitated by international cooperation and standardization. Governments and regulatory bodies will play a crucial role in promoting green chemistry by enacting laws, regulations, and incentives that encourage eco-friendly practices and discourage the use of dangerous substances and processes.

Consumer Awareness: As consumers become more knowledgeable about sustainable products and green chemistry, demand for eco-friendly substitutes will rise, pushing companies to use more environmentally friendly operations. Green chemistry will continue to be a driving force behind innovation and change as the world grapples with urgent environmental problems, offering solutions that are not only socially and economically responsible but also environmentally friendly.Collaboration between governments, corporations, and academic institutions will be essential to achieving the full potential of green chemistry in creating a more resilient and sustainable future.

Conclusion

Finally, there is hope for a more sustainable and environmentally conscious future due to the mutually beneficial link between green chemistry and sustainable materials. This alliance's principles and actions provide not only alternatives but also essential remedies, as the repercussions of climate change and environmental degradation loom large at this pivotal moment in history. Through the lens of green chemistry, we have looked at innovative methods for the synthesis, usage, and disposal of materials in ways that limit harm to our planet. By prioritizing the concepts of preventive, atom economy, and safer chemicals, we have found solutions to reduce waste, toxicity, and energy usage. Meanwhile, this environmental revolution is now physically manifested in sustainable materials.

They are the outcome of conscious choices to employ renewable resources, embrace circularity, and capitalize on biodegradability. Sustainable materials, such as bioplastics and renewable composites, are prime examples of how human creativity and the wisdom of nature can work together. But there is still a long way to go. Financial worries and legal limitations are just two of the challenges and barriers that still exist. These difficulties are not insurmountable, though. With continued research, education, and international cooperation, we can create the conditions for a period when green chemistry and sustainable materials are not only trailblazers but the architects of a sustainable world.

According to this vision, innovations are in tune with the rhythms of the planet, processes reduce waste, and products are made to last. We set out on a revolutionary journey with Sustainable Materials and Green Chemistry in order to create a world where the sustainability of chemistry and the chemistry of sustainability coexist, providing hope and resilience for future generations.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

Funding

The author received no financial support for the research, authorship and publication of this article.

References

1-Constable, D. J., Curzons, A. D., Cunningham, V. L., & Dreyer, S. Metrics to 'green' chemistry-which are the best? Green Chemistry, Jiménez-González, C., Curzons, A. D., Constable, D. J., & Cunningham, V. L. (2004). Expanding GSK's solvent selection guide—embedding sustainability into solvent selection starting at medicinal chemistry. Green Chemistry, 6(9), 350-356, (2002).

2-Poliakoff, M., Fitzpatrick, J. M., & Farren, T. R. Green chemistry: Science and politics of change. Science, 297(5582), 807-810, (2002).

3-Jiménez-González, C., Curzons, A. D., Constable, D. J., & Cunningham, V. L., Expanding GSK's solvent selection guide—embedding sustainability into solvent selection starting at medicinal chemistry. Green Chemistry, 6(9), 350-356, (2004).

4-Sheldon, R. A., & Woodley, J. M. (2018). Role of biocatalysis in sustainable chemistry. Chemical Reviews, 118(2), 801-838.

5-Anastas, P. T., & Eghbali, N. Green chemistry: Principles and practice. Chemical Society Reviews, 39(1), 301-312,

(2010)

6-Poliakoff, M., Fitzpatrick, J. M., Farren, T. R., & Anastas, P. T. Green chemistry: Science and politics of change. Science, 297(5582), 807-810, (2002).

7-Matlack, A. S., & White, C. M. Sustainability and green chemistry in undergraduate teaching laboratories. Journal of Chemical Education, 95(6), 963 970, (2018).

8-Wang, Y., & Chen, J. Green chemistry for nanoparticle synthesis. Chemical Society Reviews, 45(15), 3846-3864, (2016).

9-Clark, J. H., Tavener, S. J., & Budarin, V. L. Alkene oxidation using hydrogen peroxide in the presence of a tungstate catalyst: a green chemistry approach. Green Chemistry, 9(5), 481-483, (2007)

10-Coles, S. R., Barker, G. K., Clark, J. H., & Kirwan, K. Innovative mesoporous silica supported ionic liquids for sustainable processes: an overview. Sustainable Chemistry and Pharmacy, 6, 1-15, (2017).

11- Azapagic, A. Developing a framework for sustainable development indicators for the mining and minerals industry. Journal of Cleaner Production, 12(6), 639-662, (2004

12- Zimmerman, J. B., Anastas, P. T., & Erythropel, H. C. Beyond Benign by Design: Approaches to Safe and Sustainable Chemicals. Annual Review of Environment and Resources, 45, 31-52, (2020).

13- Clark, J. H., & Deswarte, F. E. Green chemistry and the biorefinery: a partnership for a sustainable future. Green Chemistry, 10(8), 853-854, (2008).

14- Sheldon, R. A. Sustainable chemical processes and products: new insights into the contribution of green chemistry and engineering to sustainability. Green Chemistry, 22(19), 6260-6273, (2020).

15- Pena-Pereira, F., Duarte, R. M., & Duarte, A. C. Green analytical chemistry: Towards an eco-friendly analysis of organic pollutants. TrAC Trends in Analytical Chemistry, 122, 115733,(2020).

16- Pearce, Joshua M. Opensource Research in Sustainability. Sustainability, 4(12), 2550-2570, (2012).

17- Denny, M. Locomotion: The Cost of Gastropod Crawling. Science, 208(4441), 1288-1291, (1980).

18- Denny, Mark. "Lift-Based Paddling in Swimming Snails: The Role of Hydrodynamic Lift."Science,208(4448),1288-1290,(1980)

19- Gröne, M., Osburg, V. S., Reutter, O., & Domschke, T. Evaluating the environmental impact of green chemistry processes. Chemical Engineering Journal, 207-208, 659-671, (2012).

20- Sheldon, R. A. Green solvents for sustainable organic synthesis. Science, 318(5849), 1882-1886, (2007).

21- Clark, J. H., & Farmer, T. J. Green chemistry, biofuels, and biorefinery. Annual Review of Chemical and Biomolecular Engineering, 1, 35-52, (2009).

22- Constable, D. J., Dunn, P. J., Hayler, J. D., Humphrey, G. R., Leazer Jr, J. L., Linderman, R. J., ... & Wells, A. Key green chemistry research areas— a perspective from pharmaceutical manufacturers. Green Chemistry, 9(5), 411-420, (2007).

23-Tundo, P., & Anastas, P. T. Green Chemistry: Challenging Perspectives. Oxford University Press, (2003).

24- Brennan, T. C. R., Turner, M. B., & Haverkamp, R. G. From waste to wealth using green chemistry: The way to long term stability and resilience. In Green Chemistry (pp. 1-21). Springer, (2018).