

GREEN NANOTECHNOLOGY: WHY ARE THEY IMPORTANT FOR SUSTAINABLE FUTURES?

Abstract

Green nanotechnology is pivotal for achieving sustainable futures as it merges the remarkable capabilities of nanotechnology with environmentally conscious practices. This innovative approach emphasizes the development and utilization of nanomaterials and processes that minimize adverse impacts on the environment and human health. Firstly, green nanotechnology fosters resource efficiency by enabling the precise design and application of nanomaterials, reducing waste and energy consumption. It promotes the development of eco-friendly, energy-efficient products and manufacturing processes. Furthermore, green nanotechnology prioritizes the use of renewable materials and non-toxic nanoparticles, diminishing harm to ecosystems and organisms. Moreover, it plays a vital role in pollution control, offering nanoscale solutions for remediation, water purification, and air quality improvement. Additionally, green nanotechnology contributes to renewable energy generation and storage through nanoscale materials like solar cells and batteries. In essence, green nanotechnology aligns scientific advancements with ecological responsibility, paving the way for sustainable development, cleaner technologies, and a healthier planet, thus ensuring a brighter and more sustainable future for generations to come.

Keywords: Nanotechnology, Green nanotechnology, Environmental challenges, Sustainable future

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I. INTRODUCTION

Nanotechnology, a phrase comprising the science, engineering, and applications of submicron materials, entails the fundamentally novel and beneficial exploitation of the special physical, chemical, and biological features of nanoscale substances. The research, engineering, and uses of submicron materials are collectively referred to as "nanotechnology," which refers to the fundamentally novel and beneficial harnessing of the special physical, chemical, and biological features of nanoscale materials (Narayanan *et al.*, 2012).

Richard Feynman, a well-known physicist, developed this idea in 1959 by using individual atoms to produce microscopic particles. Nanotechnology is the study, engineering, and use of submicron materials as well as the unique physical, chemical, and biological properties of materials at the nanoscale in radically novel and beneficial ways. The technique operates on a scale of nanometers, or billionths of a meter. The range of 1 to 100 nanometers is known as the nanoscale, Senjen (2007). Opportunities exist for the development of nano-properties in materials, devices, and systems that not only improve existing technologies but also offer novel qualities with potentially important technological, economic, and societal ramifications (Roco *et al.*, 2011).

Recent advances in nanotechnology have seen its power and multidisciplinary uses in the medical sciences, the creation of smart electronic materials, the production of alternative energy, the repair of the environment, and many other sectors rapidly growing (McKenzie and Hutchison 2004; Aithal and Aithal 2019). All of these developments call for the mass manufacture of a wide range of nanoparticles, both metallic and non-metallic. Environmentally sound and non-polluting methods must be incorporated into the manufacturing processes for both the manufacture of nanoparticles and finished products using nanoparticles (Raveendran *et al.*, 2003).

Green nanotechnology develops greener methods for large-scale nanoparticles production. The particles in nano dimensions (1 - 100 nm) show unique and considerably changed properties, due to their small size and large surface area to volume ratio of nanoparticles (Sharma *et al.*, 2009).

Different physical and chemical processes are currently available to synthesize nanoparticles, which allow to obtaining particles with the desired characteristics (Tsuji *et al.*, 2003; Kundu *et al.*, 2008 and Okitsu *et al.*, 2007).

II. NANOTECHNOLOGY AND THE GLOBAL SUSTAINABLE DEVELOPMENT GOALS

In 2015, the Sustainable Development Goals (SDGs) were created with the slogan "By 2030, take action to end poverty, protect the planet, and ensure peace and prosperity." The technologies of the twenty-first century capable of fulfilling these objectives include nanotechnology (NT) and information, communication, and computation technologies (ICCT). It is stated that ICCT and nanotechnology, either alone or in combination, can achieve more global sustainable goals in the allotted 15 years (Nilsson *et al.*, 2016).

Green nanotechnology is becoming a multifaceted technology with applications in all facets of society. Because of this, it will significantly affect nearly all industries and all facets of society in its advanced form by bringing cleaner, safer, and smarter goods for the home, communications, healthcare, transportation, agriculture, and all other industries. As a result, the controlled use of nanotechnology for environmental sustainability can lead to the establishment of green nanotechnology technology for sustainable development(Aitha *et al.*, 2020).

III. CONCEPT OF GREEN NANOTECHNOLOGY: GREEN AND ECO-FRIENDLY NANOTECHNOLOGY

Nanotechnologies have become a strong platform for tackling the problems of global sustainability (Diallo and Brinker 2011; Brinker and Ginger (2011). Natural substances like plant extracts, bioprosterols, vitamins, proteins, peptides, and carbohydrates can all be used to reduce the production of nanoparticles (Aitha *et al.*, 2020; Senjen 2016). One of the most promising natural reducing agents is thought to be derived from plants (Renn and Roco 2006). One area of notable achievement is the production of metal nanoparticles utilizing plant extracts as reducing agents, which is crucial for electronics and medicinal applications (Jaiswal and Mojahid 2020). Biomedical applications based on gold and silver nanoparticles, such as the delivery of medicines and genes, are currently a very active research area. Plants, algae, bacteria, and fungi are employed as harmless green reduction agents to increase biocompatibility. As a reducing and stabilising agent, plant extracts of *Salvia officinalis*, *Lippiacitriodora*, *Pelargonium graveolens*, and *Punicagranatum* were used in various methods to produce gold nanoparticles (Aithal 2016).

Green technology is a form of environmental healing that lessens environmental harms caused by the items and technologies developed for human convenience. Utilising organic natural resources is encouraged by green technology, which also avoids producing any green emissions. Additionally, they don't increase the entropy of the cosmos and utilise fewer resources. They are sustainable, enhance people's quality of life, and increase comfortability because they do not promote environmental deterioration or expand the footprint. Using the concept of green technology, the main technologies of today can be made environmentally friendly (Elia *et al.*, 2014; Prithi Rao and Aithal 2016). If adjusted to be a green technology, nanotechnology, which is anticipated to be the leading technology of the twenty-first century, will be welcomed by all users and play a crucial role in society Aithal and Rao (2016).

IV. MAIN OBJECTIVE OF GREEN NANOTECHNOLOGY

Green technology strives to address environmental problems and produce products from nanotechnology without posing a threat to human or environmental health. Green nanotechnology uses cutting-edge green chemistry and green engineering principles to produce nanoproducts without toxic materials (Boye and Arcand (2013).

Green technology uses nanotechnology to create materials while attempting to solve environmental issues without endangering the environment or human health. Modern green chemistry and green engineering techniques are used in green nanotechnology to create nanoproducts free of harmful materials (Dahlet *et al.*, 2009; Sridhar *et al.*, 2015).

V. GREEN NANOTECHNOLOGY: OPPORTUNITIES AND CHALLENGES TO ACHIEVE SUSTAINABLE DEVELOPMENT GOALS

The Sustainable Development Goals (SDG) can be accomplished by 2030 if technology is used wisely. Potential worries about the expected nano toxicity have prevented advancements in the transdisciplinary frontier technology of nanotechnology, which is valuable for novel solutions in the primary, secondary, tertiary, and quaternary industrial sectors Richman and Hutchison (2009).

For the use of nanotechnology in a variety of applications, green nonmaterial production methods are crucial. There are numerous biological and medicinal uses for the biological processes that create nanoparticles. It is challenging to sustainably provide clean water for industrial manufacturing, energy production, mineral extra (Aithal and Aithal 2022; Diallo and Brinker 2011).

VI. GREEN NANOTECHNOLOGY BASED INNOVATIONS IN DIFFERENT SECTORS (SHANNON *ET AL.*, 2008):

- 1. Agriculture:** Nano-pesticides, nano-fertilizers, nano-biosensors, and nano-enabled remediation are employed in precision farming and biotic and abiotic remediation in order to attain their maximal biological efficacy without overdosing Han and Liu. (2009). These methods involve the regulated delivery of nutrients to specific soils, as well as the morphological and physiological responses of plants and the soil biota. Environmental pollutants can be located and eliminated using nano-sensors and nano-remediation techniques Guoliang (2011).
- 2. Oil & Natural Gas:** In addition to traditional uses like cementing and well stimulation to increase well productivity, green nanotechnology offers nanoparticles for use as drilling fluids and better oil recovery.
- 3. Nano-Enhanced Cleanup Technologies:** This includes environmental cleanup and remediation, such as sewage treatment, waste management, and air and water purification. Bioreactors, infiltration, electro winning, electro coagulation, and nano bioremediation are a few examples (Aithal and Aithal (2020). Environmental pollution can be cleaned using green nanotechnology products, processes, and applications, including the air, water, and sound they produce. By reducing greenhouse gas emissions and hazardous waste levels, they also counteract climate change Aithal (2015b).
- 4. Environment Remediation:** The use of nanoparticles to remove environmental pollutants such as wastewater, ground water, soil, sediment, and others is known as nano-remediation. In order to degrade potentially dangerous compounds and novel emerging pollutants like pharmaceuticals, toxins, and hormones that may have long-lasting effects on the environment and human health, nanotechnology can be used in conjunction with solar energy and the most recent developments in nano-engineered titania photo catalysts and membranes Alex (2017). In this method, a cheap supply of clean water can be ensured. Nanotechnology can help combat climate change by developing low-carbon energy sources for the market and reducing greenhouse gas emissions Aithal (2015a).

5. **Food & Food Processing:** Detecting contamination, enhancing food storage, tracking, training, and brand protection are just a few of the uses for green nanotechnology in the food industry. It is also used to encapsulate vitamins and other nutrients, enhance flavor, add antibacterial green nanoparticles, and extend the shelf life of food.
6. **Renewable Energy:** Green nanotechnology is used for low-cost energy management systems, efficient lighting, and the generation, transmission, and storage of renewable energy.
7. **Consumer Goods Industry:** Green nanotechnology has an impact on fast consumer goods such textiles and fabrics, cosmetics and skin care, sporting goods, cleaning products, furniture, and home appliances in terms of durability, production costs, better functionality, security, etc.
8. **Medical Equipment & Drug Synthesis:** medication production, targeted medication delivery, medical diagnostics, and regenerative medicine are being revolutionized by green nanotechnology.
9. **Electrical, Electronics and Computer Industry:** The development of green, energy-efficient technologies is the emphasis of the discipline of green nanotechnology. It involves applying nanotechnology to the creation of high-speed and small-scale computer and communication devices, high-density memory chips, nano-sensors, and other parts for ubiquitous computing, wearable electronics, and entertainment devices (Hamza and Jaafar2022). There have been great developments and ground-breaking discoveries in the field of nanotechnology over the previous ten years. It is expected to be completed by 2020. Nanotechnology will be widely used, and no aspect of life will be left unaffected. Despite the fact that tremendous advances in nanotechnology have resulted in a wide range of commercial and academic applications, little is known about its potential negative consequences on human health and the environment (Hanet *al.*, 2013). Despite the exciting future of nanotechnology, there is growing concern that certain types of nanoparticles may gravely harm human health and the environment if employed carelessly or deliberately.

VII. POTENTIAL HARMFUL EFFECTS OF NANOPARTICLES

Nanotechnology has been regarded as the next industrial revolution, with applications in chemistry, health, materials science, and engineering. Disruptive developments may occur in the future as a result of molecular production, an advanced form of nanotechnology. Although the usage of nanoparticles is new, concerns about the potential toxicity of nonmaterial tied to many aspects of human existence have already been raised. The risk is as diverse as the area of nanotechnology itself, and it involves environmental, health, occupational, and socioeconomic problems (Albrecht *al.*, 2006), with certain nanoparticles being poisonous when inhaled. Nanoparticles inhalation can lead to pneumonia and cardiac issues. Nanoparticles in drug carriers are utilized to deliver medications to target cells, limiting the impact of the drugs on other organs. There is little information available Aithal and Aithal (2015).

Nanoparticles toxicity is mass-dependent and also depends on physical and chemical properties that are not routinely considered in toxicity studies (Maynord (2006). However, despite significant progress in recent years, the biological and environmental action pathways of nonmaterials remain poorly understood (World Health Organization (WHO), 2013; Loft 2012).

The potential health consequences of a chemical are determined by its toxicity and the amount of substance that can reach target organs in the body (Albrecht *et al.*, 2006; Vogel, U.(2012).It is becoming increasingly clear that greater exposure of nanotechnology researchers, workers, and consumers to potentially dangerous compounds might have negative health consequences. Because of their chemical nature, size, and potentially non-biodegradable composition, nonmaterial pose substantial difficulties in the environment, dispersing swiftly and producing bioaccumulation, the implications of which are still unknown Howard (2012). Nonmaterial, which is widely utilized in a variety of consumer products such as creams, sunscreens, and lotions, is projected to penetrate the biosphere, where its fate and behavior are largely unknown Monica andCremonini (2009); Pant *et al.*, (2023). Nanoparticles interactions with the environment might have negative consequences.

VIII. CONCLUSION

As technology advances, more efforts are being made to provide methods to analyze or measure the impact of nanotechnology on certain policy goals such as green growth. This is a really challenging task. In comparison to the risks associated with current technologies, the risks connected with future green nanotechnologies must be balanced against the human and environmental costs involved with poorly addressing key global challenges. We can reduce the risks associated with it for various industrial uses by converting nanotechnology into green and eco-friendly nanotechnology through bottom-up preparation techniques of green chemistry, which also resembles many elements of ideal technology. Nanotechnology is a general-purpose technology with characteristics such as pervasiveness, advancement, and creative possibilities.

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