**Green Nanotechnology: Why are they important for sustainable futures?**

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**Abstract**

Nanotechnology is expected to have a significant impact on the development of ‘‘clean‘‘ and ‘‘green‘‘ technologies with significant environmental benefits, which have been dubbed ‘‘green technologies‘‘. Green nanotechnology aims to provide not only nano products that solve environmental problems but also solutions for the advancement of society. The main objective of this article is to provide an overview of green technology associated with nanotechnology and its complications, current benefits and importance for a sustainable future.

**Key Words: Nanotechnology, Green nanotechnology, Environmental challenges, Sustainable future.**

**Introduction:**

Nanotechnology – a term encompassing the science, engineering, and applications of submicron materials– involves the harnessing of the unique physical, chemical, and biological properties of nanoscale substances in fundamentally new and useful ways. Nanotechnology – a term encompassing the science, engineering, and applications of submicron materials – involves the harnessing of the unique physical, chemical, and biological properties of nanoscale substances in fundamentally new and useful ways.

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.

There are opportunities to develop materials, devices, and systems with nano-properties that not only enhance current technologies but also provide novel features with potentially significant technological, economic, and societal repercussions. [1].

Recent developments in nanotechnology have witnessed the rapidly evolving power and its interdisciplinary applications in medical sciences, in the development of smart electronic materials, in alternative energy generation, in environmental restoration and in various allied fields [2–14]. All of these advancements require the production of a large variety of nanoparticles, including both the metallic and non metallic, in large scales. It is imperative that the manufacturing processes, for both nanoparticles production and nanoparticles embedded finished products, incorporative environmentally sound and non polluting technologies.

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.

Different physical and chemical processes are currently available to synthesize nanoparticles, which allow to obtaining particles with the desired characteristics [3, 4, 5].

**Nanotechnology and the Global Sustainable Development Goals:**

The Sustainable Development Goals (SDGs) were established in 2015 under the tagline "By 2030, take action to end poverty, protect the planet, and ensure peace and prosperity." Nanotechnology (NT) and Information, Communication, and Computation Technologies (ICCT) are twenty-first-century technologies capable of achieving these goals. It is stated that ICCT and nanotechnology, either alone or in combination, can achieve more global sustainable goals in the allotted 15 years [10].

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 [11].

**Concept of Green nanotechnology: Green and Eco-friendly nanotechnology:**

Nanotechnologies have become a strong platform for tackling the problems of global sustainability [12–13]. Nature offers us a wide range of compounds that can be employed to lessen the formation of nanoparticles, including plant extracts, bioprosterols, vitamins, proteins, peptides, and carbohydrates [14–15]. Plant extracts are regarded as one of the most promising natural reducing agents [16]. 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 [17]. Biomedical applications based on gold and silver nanoparticles, such as the delivery of medicines and genes, are currently a very active research area. To promote biocompatibility, nontoxic green reduction agents like plants, algae, bacteria, and fungi are used. Different methods were explained to create gold nanoparticles by using plant extracts of *Salvia officinalis*, *lippia citriodora*, *pelargonium graveolens*, *punica granatum*, as a reducing and stabilization agent [18].

Green technology is a form of environmental healing that lessens environmental harms caused by the items and technologies developed for human convenience. Green technologies encourage the utilization of organic natural resources and forgo the creation of green emissions. Additionally, they use fewer resources and don't contribute to the universe's entropy being increased. Since they do not encourage environmental deterioration or add to the footprint, they are sustainable, improve people's quality of life, and increase human comfortability. Using the concept of green technology, the main technologies of today can be made environmentally friendly [19 -28]. 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.

**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 [29].

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 [30].

**Green Nanotechnology: Opportunities and Challenges to Achieve Sustainable Development Goals**

If technology is applied effectively, the Sustainable Development Goals (SDG) can be achieved by 2030. The trans disciplinary frontier technology of nanotechnology, which is useful for novel solutions in the primary, secondary, tertiary, and quaternary industrial sectors, has been held back by potential concerns about the projected nano toxicity [31].

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 [32, 12].

**Green nanotechnology based innovations in different Sectors** [33]**:**

**Agriculture:** In order to achieve their maximum biological efficacy without overdosing, nano-pesticides, nano-fertilizers, nano-biosensors, and nano-enabled remediation are used in precision forming and biotic and abiotic remediation. These techniques involve the controlled release of nutrients to targeted soils, soil biota, soil organic matter, and plant morphological and physiological responses. Nano-sensors and nano-remediation methods can be used to identify and get rid of environmental pollutants.

**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.

**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 [34]. 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.

**Environment remediation**: The use of nanoparticles to remove environmental pollutants such as wastewater, ground water, soil, sediment, and others is known as nano-remediation. Nanotechnology can be used in conjunction with solar energy and the most recent advancements in nano-engineered titania photo catalysts and membranes to degrade potentially hazardous compounds and novel emerging pollutants like pharmaceuticals, toxins, and hormones that may have long-lasting effects on the environment and human health [35]. 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.

**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.

**Renewable Energy**: Use of green nanotechnology for renewable energy generation, transmission, storage, efficient lighting, and energy management systems at low cost.

**Consumer goods industry:** In terms of durability, production costs, improved functionality, security, etc., green nanotechnology has had an impact on fast consumer items such textiles and fabrics, cosmetics and skin care, sporting goods, cleaning products, furniture, and home appliances.

**Medical equipment & Drug synthesis:** Green nanotechnology supports to revolutionize drug manufacturing, targeted drug delivery, medical diagnostics, and regenerative medicines.

**Electrical, Electronics and computer industry**: Green nanotechnology is a field that focuses on the creation of environmentally friendly, energy-efficient technologies. It entails the use of nanotechnology to the development of high-speed and miniature-sized communication and computation devices, high-density memory chips, nano-sensors, and other components for ubiquitous communications, computing, embedded wearable electronics, and entertainment devices. [36].

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 [37]. 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.

**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 [38], 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.

Nanoparticles toxicity is mass-dependent and also depends on physical and chemical properties that are not routinely considered in toxicity studies [39]. However, despite significant progress in recent years, the biological and environmental action pathways of nonmaterials remain poorly understood [40-42].

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 [38, 43]. 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. 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 [44]. Nanoparticles interactions with the environment might have negative consequences.

**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 [45]. 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 [46]. Nanotechnology is a general-purpose technology with characteristics such as pervasiveness, advancement, and creative possibilities.

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