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Nanotechnology in forestry: Revolutionizing sustainable forest management and products

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Abstract
As an emerging industry, nanotechnology has high application prospect in the development of the forested based industry. This type of nanomaterials has the specific ability of processing material in the nano level that has definite prospect in resolving the problems which confront conventional forestry techniques. However, given the growing global demand for valuable and high-strength wood products, and the concern for the sustainable uses of the forest resources, nanotechnology has emerged as novel promising avenue. Despite, the fact that nanotechnology in forestry is at its infancy; there are possibilities of application of nanotechnology in environmentally friendly new material production, in monitoring the environment, in nutrient delivery, and timber protection. There are also new innovative technologies under research and development include; nanosensors, nanofertilizers and advanced coatings. With this, improvements may include enhanced growth rates, enhanced capability to pests and other environmental stress factors, decreased requirement for inputs such as water and fertilizers and greater commercialization of valued wooden goods. Such types include water-saving nanomaterial, nanomaterial for carbon capture, and fungicidal/antibacterial nanomaterial for preservation of wood, which are more sustainable in terms of their impact to the forest as well as the economy. However, this technology surprisingly provides details with adverse environmental and health consequences, cost of production, and most importantly the lack of softer measures such as: adequate legislation. Nanotechnology opens up unprecedented opportunities to solve challenges faced by traditional forestry methods. With the ever-increasing global demand for high-performance wood products and the sustainable management of forest resources, nanotechnology is now recognized as a possible innovative direction. Although nanotechnology in forestry is an emerging field, opportunities exist in eco-friendly material development, environmental monitoring, nutrient management, and wood protection. Innovative technologies are also being studied and developed such as nanosensors, nanofertilizers and advanced coatings. Improvements may include increased growth rates, improved pest resistance and tolerance to environmental stress, reduced resource inputs, and high-value wood products. Applications of nanomaterials include water-saving nanomaterial, nanomaterials for carbon capture, and nanomaterials as wood preservatives, all of which enable ecologically and economically more sustainable forestry. However, this technology, unfortunately, presents details with negative environmental and human health impact, the production cost, and the absence of appropriate regulatory frameworks. The challenges of risk assessment for incorporating nutrition knowledge, standardizing testing mechanisms and the effects of nanomaterials on the environment can only be addressed through the ongoing research. It takes a lot of work to ensure the safety and stabilization of nanotechnology in the future. This will include formulation of policy, sensitization of the public domain and collaborations with other scholars. By responding to these requirements, the forestry industry will be well positioned to exploit nanotechnology in a manner that fosters innovation, sustainability and international environmental goals.

Keywords: Nanotechnology, risk assessment, wood protection, environment, carbon nanotube, wood preservatives

Introduction

The term 'nanotechnology' was first formally proposed by Norio Taniguchi in the year of 1974 at the University of Tokyo. The name Nano comes from the Greek word "Nanos" meaning "dwarf", it defines a scale that is one billionth, or 10^-9 of meter — or one thousandth the size of a micron. These dimensions are beyond visible light indeed since these are molecules (Falchi *et al*., 2018) [9], though Mansoori & Soelaiman (2005) [22] pointed out that they are far beyond naked eye limits. This paper discusses role of nanotechnology in the twenty-first century. It concerns the properties of nanomaterials and their interactions with environment and living organisms, when sized 1-100nm. Nanomaterial according to one of the most well-known definitions is a material in which one or more particles have at least one dimension between one and one hundred nanometres. This realization that at such a small-scale novel property come into plays that can aid in solving so many technical or social problems (Haokip, 2023) [13]. The sector involving nanotechnology as the science and technology of manipulating and developing substances on a nanoscale is recognized to be expanding at a comparatively fast pace. Nanotechnology is the understanding of the characteristics and use of material and devises having at least one dimension ranging from one to a hundred nanometers because at this dimension the properties of matter are distinct for a variety of uses and is used to describe a scale that is one billionth or 10^-9 of a meter or about 1,000 times smaller than a micron. These dimensions are far beyond naked-eye limits (Mansoori & Soelaiman, 2005) [22], as these are tiny molecules (Falchi *et al*., 2018) [9]. Nanotechnology has its impact on the economy, industries, and life of the people in the twenty-first century. It relates to the physical, chemical, and biological properties of nanomaterials (1-100 nm) and their impact on human life. A key definition of a nanomaterial is that it is a material that contains particles at least one dimension of which lies between 1 to 100nm. This realization that at such a small-scale novel property come into play that can aid in solving a myriad of technical or social problems (Haokip, 2023) [13].

Nanotechnology is the science and technology of manipulating and developing substances on a nanoscale, this sector is rapidly growing. It is the study of materials and devices with the scale of 1-100 nanometers, so at this scale, the properties of matter can be manipulated for a great number of purposes because they are unique. Recent developments in nanotechnology have impacted many sectors for instance, medical, electronics, energy and even environmental conservation. Scientists have applied it to create materials with characteristics that have never existed before, including stronger and lighter structural materials, self-cleaning substrates, bioengineered organs, and tissue constructs. Is used to describe a scale that is one billionth or 10^-9 of a meter or about 1,000 times smaller than a micron. These dimensions are far beyond naked-eye limits (Mansoori & Soelaiman, 2005) [22], as these are tiny molecules (Falchi *et al*., 2018) [9]. Nanotechnology has its impact on the economy, industries, and life of the people in the twenty-first century. It relates to the physical, chemical, and biological properties of nanomaterials (1-100nm) and their impact on human life. A key definition of a nanomaterial is that it is a material that contains particles at least one dimension of which lies between 1 to 100nm. This realization that at such a small-scale novel property come into play that can aid in solving a myriad of technical or social problems (Haokip, 2023) [13].

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Nanotechnology is recognized in terms of its properties including (a) low volume and medium demands, (b) properties at an individual/small scale and potentials at a larger scale, and (c) the optimum production scale in a new generation fabrication (Mohieldin *et al*., 2011) [25]. Over recent years, great potential of nanotechnology applications has emerged. It has generated considerable interest worldwide because it has versatile uses in various sectors such as paper and pulp, food and packaging, agriculture and forestry, plant protection, food crops, health, automobile, construction, sensors and electronics etc. Although these applications are presently still only experimental, their commercial use is gradually becoming imminent for a broad market. The use of particular nanotechnology in any kind of forestry and forest products and service from growing and managing the forest, harvesting it and using it in any kind of wood production and the usage of the wood-based products and services has a great potential. This will assist in enhancing tree vigor through protection from pests and diseases, establish toxicity of the soils, and enhancing tree vigor by optimizing cell photosynthetic rate. Nanotechnology offers good potential for the forest-based economy (McCrank, 2009) [23].

Nanomaterials have numerous potentials uses in environmental applications; however, both nanotechnology practitioners and environmental scientists are inclined to the negative impacts of the nanomaterials on environment and the biological systems. This is because the environment's fate of nanomaterials and nanoparticles related to them is convoluted. Such nanoparticles are believed to persist in the atmosphere, water bodies, and soil, and impact plants and animals in water and on land, with adverse impacts on the human ecosystem (Singh *et al*., 2021) [34].

Applications of nanotechnology in the forestry sector are still in the initial stages with major developments recorded around the protection of wood, nutrient management, environmental sensing and composite materials. UV resistant nanocoatings, nanometal preservatives and nano fertilizers have displayed a possibility to enhance the life expectancy of wood, enhance tree growth and also enhance soil health. Scholars are also exploring applications of nanosensors for precise tracking of forest habitats and on the other extreme nano-cellulose and nanowood are gradually finding their way to the market for green packaging and constructing. However, costs and risks remain high, regulation either unavailable or unsuitable, and environmental and health implications limit its use. These types of nanotechnology application in forestry mentioned above are also needed continued research, policy, and cooperation.

Applications of Nanotechnology in Forestry

Nanotechnology applications in forestry are so far quite limited but research is being conducted. The following are some of the ways which the nanotechnology industry can be useful to the forestry industry. Nanoparticles are materials that have dimensions of less than one hundred nanometers as is implied by their name. They may be metal, ceramics, polymers, or any other material (Jirous-Rajkovic & Miklecic 2021) [15]. In the field of nanotechnology, a variety of opportunities can be discussed in the forestry sectors, these include; nano-fertilizers and nano-additives (Fig.1).

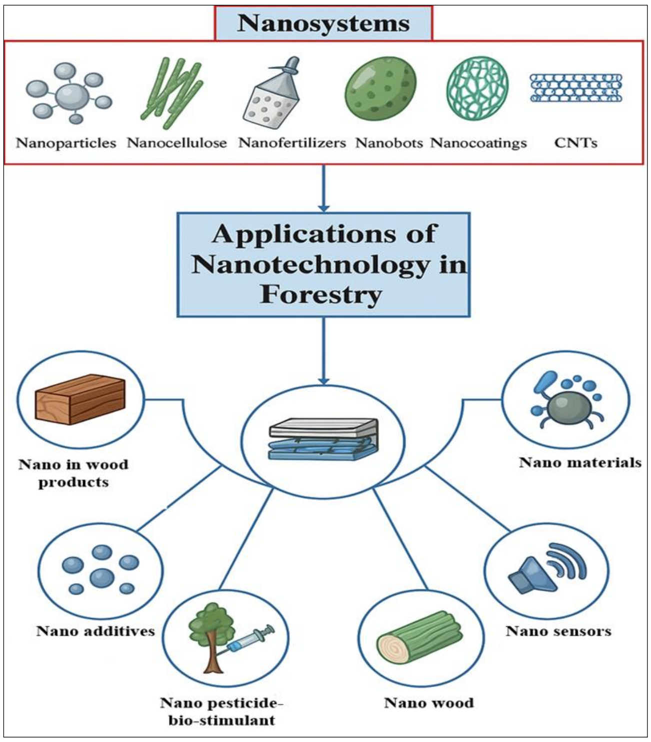

Fig 1: Overview of the principal application areas of nanotechnology in forestry

1. Nanofertilizers and Additives

Nanofertilizers are substances with a nanoscale size, in a particulate system of nanoparticles, used for controlled release of macro- and micronutrients to plants (DeRosa *et al*., 2010; Adisa *et al*., 2019; Shang *et al*., 2019) [1, 7, 32]. Research has proven that they enhance crop yield by 30% higher than that obtained from the normal synthetic fertilizers (Kahe *et al*., 2018) [16]. Applying them at a magnitude lower than conventional fertilizers can minimize leaching and runoff and the emission of gaseous wastes into the atmosphere. These nanofertilizers may be the significant development in the company and the protection of the environment (Mejias *et al*., 2021) [24].

Nanofertilizers which are made of nanoparticles may help to transform the forestry industry through enhanced nutrient absorption, soil health and plant health (Nongbet *et al*., 2022) [26]. Nanofertilizers are easier to be absorbed by plants and this cause improved nutrients intake and assimilation by the plants (Yadav *et al*., 2023) [38]. This measure can go along way in stimulating tree growth and productivity in forested areas. Most of the fertilizers used in the past are washable; hence, they cause pollution in the environment. Nanofertilizers are designed to ensure efficient supply of increases nutrient use efficiency, and seek to enhance sustainable nutrient use in the forestry (Nongbet *et al*., 2022) [26].

The application of nanofertilizers in production forestry has a variety of benefits which includes- Biological propriety of raises vitality and biodensity of soil apparatus, nutrient increments, water reduction, water efficient mastery and other (Singh *et al*., 2021) [34]. Many plants wash out inorganic fertilizer hence it becomes unavailable to the plants. For instance, Obbódi & Saigusa (2000) [28] observed that about 40 – 70% of nitrogen, 80 – 90% of phosphorus and 50 – 90% of potassium fertilizers get either lost or fixed in the soil, hence causing the losses. It would be possible to strengthen the regular fertilizer particles by adding nanomaterial, because these have a higher surface tension than the typical fertilizer particles to control the release of nutrients (Brady &Weil, 1999) [5]. Indeed, despite the huge benefits which nanofertilizers could bring out to the forestry, they are also known to have risks and limitations, including the risks to human health and the environment. Nanofertilizers can improve soil nitrogen and phosphorus contents; this is important in the enhancement of soil microbial activity (Yadav *et al*., 2023; Singh *et al*., 2015) [33, 38]. This will assist help in maintaining forest ecosystems sustainability for future generations.

2. Nanobots and Nanowood

Some industrial robots come in small sizes that they cannot be seen other than with an electron microscope; they are referred to as nanobots. They are used in a forestry to enhance the growth of plants. Nevertheless, the extent of their applications should be subjected to technical analysis of their effects on the environment. Using the term nanotechnology for the first time in 1959, physicist Richard Feynman presented to the creative opportunity of atom-assembled devices as stated by Freitas (2005) [10].

Nanowood is a processed wood-based material where the characteristic of wood is used to manufacture insulation products and the result comes out as a very light weight, highly durable, biological based insulation material. Its molecular structure is disposed in parallel-aligned fibers and, therefore, heat conduction is possible longitudinally within the fiber, while heat convection across the material is hindered by a material barrier. This also makes the nanowood a great thermal conductor being one of the best thermal insulators known to mankind. Also, cheap resources of lignocelluloses can open up beautiful prospects for the use of wood in connection with versatile large-scale uses (Li *et al*., 2018) [20].

3. Nano in Wood Products/Science

There are countless uses for nano in wood. It can be leached to wood through coatings, preservatives/nanocarrier, modified resin, wood composites, nano clay filler, derived nanomaterials, and testing such as nanoindentation. Direct application of nanometals as wood preservatives: zinc and copper. This is particularly useful for refractory wood species, for which active metal ions generally cannot penetrate into the wood, and a nanocarrier enhances penetration (Sapprasert & Clausen, 2012) [31]. Borges *et al*., (2018) [3] have suggested this as a possible way to address the challenge of developing low-toxicity, cost-effective wood preservatives. A layer of nanocoatings can indeed prolong the life of wood and non-wood products (Jasmani *et al*., 2020) [14] as each nano coating acts as a barrier to wear, moisture, and external factors. This aids in increasing product durability by reducing the need of frequent replacements and resources involved in it. It also studied to enhance UV protection for UV, solvent, and waterborne coatings to protect the wood surfaces. UV absorbers (UVA) are used to prevent lignin degradation due to UV radiation. UV absorber surface coatings are widely considered to be a fast and low-cost solution for commercial use (Rajkovic & Miklecic, 2021) [29]. One potential application is nanocoatings, which can enhance the flame-resistant properties of timber structures (Vakhitova, 2019) [37]. So, the dangers come, but so do the materials to help make structures in forested areas more durable and safer. Nanoparticles are a way to change the physical and physical properties of wood, improving its strength and durability. According to researchers, using a nano-based compound to treat four wood species significantly reduced average transverse swelling (Sahin & Mantanis, 2011) [30].

Nanotechnology can transform material derived from forests into high value products. It can help the forestry sector to discover new horizons and play its role in the economy (Taghiyari *et al*., 2020) [36]. This may facilitate the design of novel wood-based items with enhanced properties and extended service lifespan. Nanocoatings can also be engineered to possess self-cleaning and anti-fouling properties, which helps minimize the cleaning and maintenance of forest products and buildings (Jasmani *et al*., 2020) [14]. And this can save time, labor, and resources over the long run. In addition to wood, bamboo has been modified, coated, and used as nanocarriers, nanosheets, and nano clay fillers by nanostructures (Sun *et al*., 2022) [35]. The addition of carbon nanotubes has been utilized to improve the properties of wood-plastic composites.

It is yet to be determined whether there are any environmental and health issues associated with nanoparticles. Lavicoli *et al*., (2017) [19]; similarly, we have barely begun to understand the fate, transport and biological reactivity of nanoparticles in the environment and much more research is needed before potential dangers can be identified. Proper risk assessment and management procedures need to be developed so that the safe use of nanotechnology in forestry.

4. Nano-materials/Nano-sensors in Forestry

Nanomaterials have become an essential component of forestry products. Although these substances can improve the quality and longevity of wood products, their use also carries potential environmental risks. Another option is to use nanosensors, which can check soil moisture, nutrient levels, and even identify pests and diseases in plants (Singh *et al*., 2021) [34]. In this context, SPR sensors, SAW devices, QCM devices, ISEs, CNTs (Zed *et al*., 2009; Kaushik *et al*., 2015) [17, 40] are utilized to assess and measure parameters like gaseous exchange, requirement of water, etc., and can therefore be effectively used to determine the ecological services provided by forests at the microscale. Carbon nanotubes (CNTs) are hollow, cylindrical, tubular structures made of carbon atoms arranged in hexagonal lattices. CNTs can either be single-walled or multi-walled, depending on the production process employed (Hajilounezhadet *et al*., 2021) [12]. The data collection potential of nanosensors, which can collect data about the subject without requiring them to change their behavior, opens doors to new ways of tracking wildlife (Kumar *et al*., 2020) [18].

When nanosensors are incorporated in wood and paper products, they can measure (i) the applied forces, (ii) the loads and/or (iii) other variables, thus providing valuable information regarding the structure and performance of all kinds of engineered wood and paper products (Beegum & Das, 2022) [2]. This could lead to more sturdy and stable materials with wide variety of applications. They can also take accurate readings of various environmental parameters, such as temperature, humidity, and pollution level (Dincer *et al*., 2018) [8]. Additionally, it is used for monitoring water quality, availability and usage in the forest ecosystems which leads to improved water resources management and sustainability of forest ecosystems. Nanosensors have the potential to revolutionize various industries and applications, with enhancements over traditional approaches that provide substantial benefits in forestry. For example, researchers have employed it for the detection and monitoring of forest fires, allowing for early warning systems and providing near real-time information on the behavior and spread of the fire (Singh *et al*., 2021) [34]. Such data could aid firefighters and managers of the woods in better understanding and responding to the flame. Nanomaterials play a critical role, but their reactions with other environmental contaminants may increase their phytotoxicity or their behaviour (Zhang *et al*., 2022) [41]. Understanding these interactions is critical to determining the net environmental impact of nanomaterials. At this stage, the long-term environmental effects of nanomaterials are not well characterized. Additional research is needed to evaluate possible impacts on ecosystems, biodiversity, and ecosystem services (Gambardella & Pinsino, 2022) [11]. Additionally, it is vital that more research and development is done in this area to better explore the potential of sensor methods for the forestry industry. Nanotechnology for the management of water resources in forest ecosystems: By introducing water-saving nanostructure materials, forests are able to address dry conditions and enhance productive ability (Singh *et al*., 2021) [34].

5. Nano-cellulose in Forestry

Nanocellulose is a very light, firm and even edible plant material from wood pulp that has potential in a wide range of industries from forestry. With small-diameter trees and woody biomass left over that would be otherwise wasted, Nanocellulose can be produced (Zed *et al*., 2019) [39]. This not only reduces the amount of waste generated in the forestry industry but also offers an eco-friendly source of nanocellulose for diverse applications. Additionally, it may also be used as reinforcement in several polymeric materials, produced stronger and lighter composite materials adapted for building, packing, and transportation (Norizan *et al*., 2022) [27]. These materials outperform traditional options while offering a more sustainable solution. It could even enhance the quality and characteristics of forest products such as wood and paper. These items can become either stronger, more durable, or possess other desirable attributes through nanoparticles (Taghiyari *et al*., 2020) [36]. Nanosensors are microscale devices that can sense and measure many different characteristics, and may be helpful for forestry. For instance, nanosensors can be deployed to monitor the growth and development of trees, leading to more targeted and effective harvesting and resource management practices (Beegum & Das, 2022) [2]. Contributing to reduction of waste and enhancing overall sustainability in the forestry sector.

6. Nanotechnology-Driven Stem Injection: A new strategy for precision tree management

A futuristic strategy for enhancing tree growth and resilience involves the precise injection of nanoparticles directly into the stem, enabling targeted regulation of key physio-biochemical processes. By introducing engineered nanoparticles through a controlled delivery system, such as stem injection, these particles can efficiently travel through the vascular network (xylem and phloem), optimizing physiological functions at a cellular level. This innovative approach holds potential for improving photosynthesis efficiency by boosting chlorophyll activity, enhancing stress tolerance against environmental challenges like drought and salinity, and optimizing nutrient uptake by facilitating root absorption of essential minerals. Furthermore, nanoparticles can play a crucial role in hormonal regulation, ensuring balanced growth and metabolic functions. As nanotechnology advances, this method could revolutionize precision forestry and agroforestry, offering sustainable solutions to improve tree productivity, carbon sequestration, and ecosystem resilience in the face of climate change.

Future developments and potential challenges in the use of nanotechnology in forestry may include

The future developments and potential challenges in the use of nanotechnology in forestry may include (Fig.2):

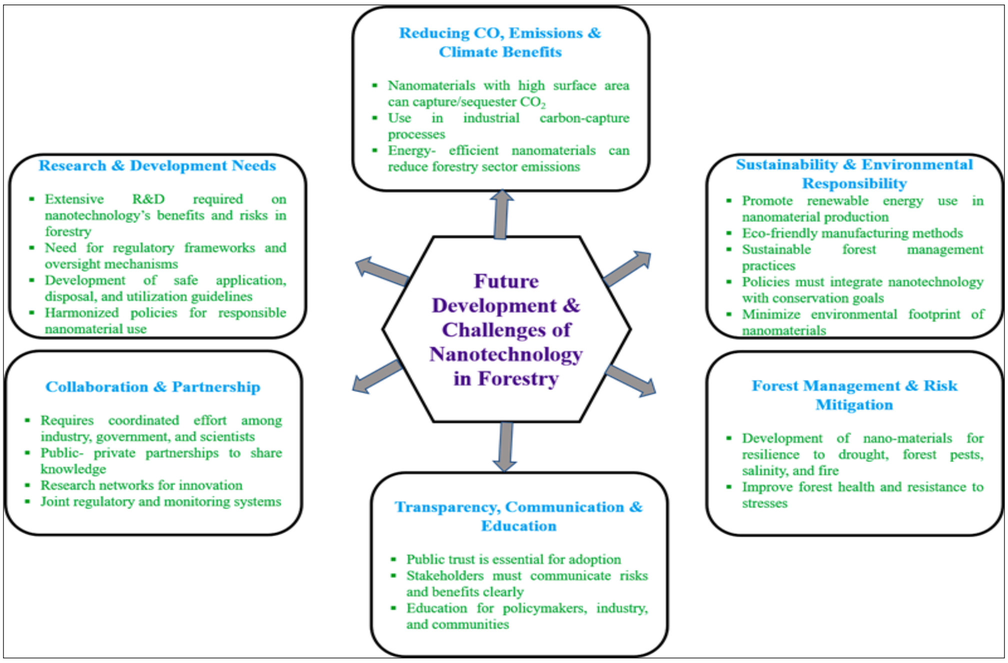

Fig 2: Key future developments and challenges associated with the use of nanotechnology in forestry

1. Research and Development

The scope of research and development definitely needed in association with nanotechnology usage in forestry with potential advantages and disadvantages for forests through nanotechnology usage, applications and products. Supporting the effective use of nanotechnology in forestry will demand frameworks and supervision practices that will be used to constraint its responsible use. This will take a collective effort between government, industry and the scientific community to identify and agree upon appropriate regulations and protocols to safeguard the health. That will involve clear regulatory frameworks and oversight mechanisms that can provide the assurance that nanotechnology is used safely and responsibly in forestry applications. This may include participation in the harmonization and provision of guidance in the application, disposal and utilization of nanomaterials in forestry and the establishment of regulatory bodies that hold the competence to fast track the amendments of the guidelines. Overall, nanotechnology in forestry needs to be promoted, but research and policy development and legislation should be done to ensure safety and sustainability.

2. Transparency, Communication, and Education in Nanotechnology

Stakeholders will need to build the trust of the public and one another, so transparency and open communication will be essential for developing foundations for a successful implementation of nanotechnology in forestry practices. All stakeholders and the general population must be exposed to the potential benefits and potential risk products and practices of nanotechnology, this will help devise more assertive communication strategies. Promoting the acceptability of this technology to a greater segment of society and educating the lay population about its potential pitfalls and advantages will also be essential to its popularization. This may involve designing and implementing educational initiatives and resources for stakeholders in the industry, lawmakers, and the wider community, as well as promoting public engagement and conversations surrounding the problem. Research in these areas will help realize the full potential of nanotechnology in establishing next generation advanced forestry industry.

3. Sustainable Development

There should be a significant focus on sustainability in the context of nanotechnology and its application in forestry. This may involve the implementation of sustainable energy sources, the improvement of eco-conscious manufacturing techniques, and the empowerment of practical woodland management practices. The creations of sustainable forest management techniques that consider the potential advantages and hazards of nanotechnology should be given top priority in policymaking. To achieve this goal, it may be necessary to promote renewable energy sources, environmentally conscious production methods, and sustainable forestry practices that reduce the negative effects of nanomaterials on the environment.

4. Collaborate and Partner

As is the case with any emergent technology, the establishment of a safe and sustainable nanotechnology-based forestry industry will demand collaboration and partnership between industry stakeholders, government agencies, and the scientific community. Such models could include industry associations; research collaborations; and public-private partnerships that will allow for the transfer of knowledge as well as co-creation of new knowledge. A coordinated effort between stakeholders and the government, industry, and scientific community will be necessary to establish a safe and sustainable nanotechnology-based forestry industry as a whole. The development of nanotechnology for forestry that delivers net benefits while avoiding or minimizing potential risks and impacts is possible if we meet the key requirements outlined collectively above.

5. Forest Management and Risk Mitigation

Nanotechnology can also be useful to develop new nanomaterials for the management of forests and many threats such as drought, flood, salinity, fire, invasion and viruses. Such nanomaterials may facilitate the resiliency and health of the forest, thus cassating for careful and robust forest management (Singh *et al*., 2021) [34]. The industry is still in its early years, and many of the fears about the products in the long term, especially their effects on human health and the environment, are nascent and need decades of study before we really know them. Therefore, research should focus on the development of standardized risk assessment methods and test protocols for the determination of the safety of forestry products and practices based on nanotechnology.

6. Reduce the emissions of carbon dioxide

Nanomaterials, which have high surface-area-to-volume ratios, can absorb carbon dioxide from the atmosphere and sequester it effectively. Industrial processes employ these materials in emissions-capture from the burning of fossil fuels, reducing the amount of CO_2 released into the atmosphere (Kumar *et al*., 2020) [18]. Nanotechnology can also be used in the forestry sector for energy-efficient methods and materials. It would also render the industry less energy-consuming and eco-friendlier (Singh *et al*., 2021) [34]. Future studies should focus on the characterization of efficient strategies and methods for analyzing the modes of emission and the fates of nanomaterials in the environment. For that, new sensors and monitoring technologies would need to be developed: to track nanoparticles as they travel through the systems of soil and water.

Limitations in Using Nanotechnology in Forestry

Developing and implementing nanotechnology in forestry comes at a significant cost. Many nanomaterials are still in their early stages of production, which may limit their widespread use in the industry. The regulatory environment for nanotechnology is still emerging, and specific guidelines and regulations are required to oversee its usage in the forestry industry (CRS Report, 2011) [6]. This involves concerns like labeling, safety testing, and nanomaterial disposal. It can be difficult to integrate nanotechnology into conventional forestry operations and infrastructure. This involves challenges such as compatibility with existing equipment, worker training, and modifying management methods to accommodate nanotechnology. Creating solutions for seamless integration is critical for the successful implementation of nanotechnology in forestry. Nanomaterials have the potential to harm a variety of creatures in the environment, including plants, animals, and microorganisms (Zhang *et al*., 2022; Gambardella & Pinsino, 2022) [11, 41]. Elements such as their chemical composition, size, form, and surface chemistry influence the ecotoxicity of nanomaterials (Liu *et al*., 2022) [21]. The ecotoxicity of nanomaterials must be properly assessed in order for them to be used safely in forestry and other industries. Nanomaterials have the capacity to accumulate in animals and biomagnify along food chains, resulting in larger concentrations and enhanced toxicity at higher trophic levels (Boros & Ostafe, 2020) [4]. This can have long-term effects on ecosystems and the organisms within them.

Conclusion

The forestry sector has significant potentials for nanotechnology implementation. More investment are needed to bring safe science-based research and policies, products and nanotechnology processes to forestry. There is need to establish evaluation methods and a uniform testing regime for evaluating the possible dangers of nanomaterials prior to deploying them. There is a need of appropriate means of environmental monitoring to detect the release and distribution of nanomaterials as well. Furthermore, implementation of standards, guidelines, and regulatory moves will promote responsible production, use, and disposal of nanomaterials for forestry applications. Public awareness and engagement activities are very important for an increased trust by the public and better understanding of the opportunities and risks associated with nanotechnology. These measures are one way in which nanotechnology can be utilized to foster progressive measures to make the forestry sector a more sustainable terrain, while mitigating risks and impacts.

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