Green Nanotechnology: A Roadmap to Long-Term Applications in Biomedicine, Agriculture, Food, Green Buildings, Coatings, and Textile Sectors

Meesala Krishna Murthy, Pratima Khandayataray, Dibyaranjan Samal, Rojalin Pattanayak, and Chandra Sekhar Mohanty

Abstract As the result of the growing world population, the availability of resources is decreasing. Creating new non-polluting technologies is essential for the long-term prosperity of human society. Eco-friendly and sustainable technologies can be developed with nanotechnology, which will benefit humans and the environment. In green nanotechnology (biosynthesis), nanomaterials and nanoparticles are formed through biogenesis. Biomedical, nutrition, environmental remediation, coating, textile, and agricultural fields are some of the many applications of green nanotechnology. Many regulatory processes rely on green nanotechnology due to its small size. Better biological diagnosis, better quality of food, agriculture input reductions, better absorption of soil nanoscale nutrients, environmental cleanliness, and clean energy supply are some of the many potential benefits of green nanotechnology. Green nanoscience and technology can address current and future problems in the biomedical and food industries as well as society. These include issues of sustainability, sensitivity, and human welfare. The areas discussed in this chapter include biomedical, food, environmental remediation, coatings, textiles, and agriculture.

M. K. Murthy (✉)
Department of Allied Health Sciences, Chitkara School of Health Sciences, Chitkara University, Punjab 140401, India
e-mail: krishnameesala6@gmail.com

P. Khandayataray
Department of Biotechnology, Academy of Management and Information Technology, Utkal University, Bhubaneswar, Odisha 752057, India

D. Samal
Department of Biotechnology, Sri Satya Sai University of Technical and Medical Sciences, Sehore, Madhya Pradesh 466001, India

R. Pattanayak
Department of Zoology, College of Basic Science and Humanities, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha 751003, India

C. S. Mohanty
Plant Genetic Resources and Improvement Division, CSIR-National Botanical Research Institute, Lucknow, Uttar Pradesh 226 001, India

T. Khan et al. (eds.), *Nanomaterials: The Building Blocks of Modern Technology*, Smart Nanomaterials Technology, https://doi.org/10.1007/978-981-99-4149-0_12

Keywords Green nanotechnology · Human health · Food and agricultural applications · Coating and textile applications · Environmental remediation

1 Introduction

According to Bhainsa and D'souza [27] and Shahverdi et al. [192], nanotechnology is primarily concerned with objects, materials, and devices that have a diameter of less than 100 nm (nm). Nanomaterials have gained prominence over the past decade in medical, pharmaceuticals, agriculture, coating industries, energy production, nanostructured electrodes in batteries, communication technology devices, and food and textile industries [43, 49, 186].

Despite the many applications and benefits of synthetic nanoparticles, their synthesis is expensive and their by-products are environmental hazards [132]. Therefore, scientists and researchers are showing keen interest in green nanoparticle synthesis [153]. A green nanotechnology is an approach that uses renewable resources as opposed to physical and chemical nanotechnology [6, 117, 164], because it is less expensive, less energy-consuming, eco-friendly and causes no harm to humans [5, 10, 98, 205] (Fig. 1). Biological materials are used in the production of nanomaterials in green nanotechnology [16, 26, 63, 163, 195, 198, 205] (Fig. 1).

The field of green nanotechnology is an important subset of green chemistry and green engineering. This minimizes power and fuel consumption wherever possible [220]. In green chemistry, there are 12 principles (Fig. 2) which are being used by Scientists, engineers, and chemists worldwide because they produce less harmful chemical products and by-products [11, 12, 124, 148]. Aside from synthesizing sustainable nanoparticles [155], green nanobiotechnology also saves raw materials, energy, and water, reduces greenhouse gases, stops adverse effects before they occur, and contributes significantly to environmental and climate protection [103, 220, 242].

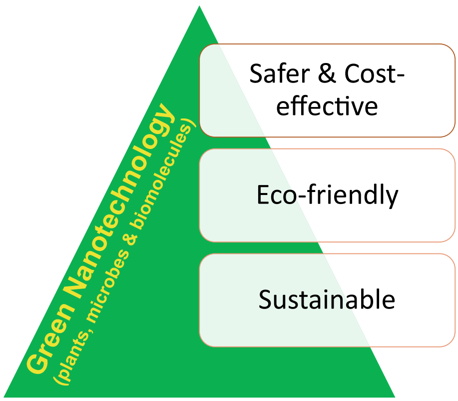

Fig. 1 Main goals and materials used for green nanotechnology

Fig. 2 Green chemistry principles for green nanotechnology

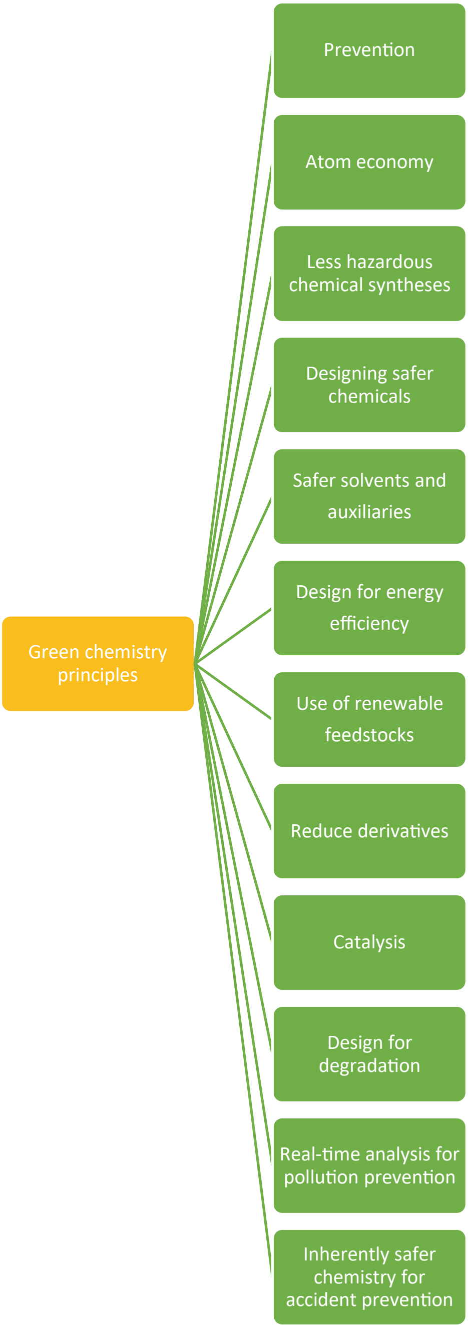

Figure 3 shows green nanotechnology applications which may involve in cosmetics, nanofabrication, bioengineering, energy production, green building constructions, medicines and drugs, nanobiotechnology, optical engineering, agriculture, food and coating industries, etc. [220]. To make a conclusive assessment, green nanotechnology requires a complete process assessment like any other industrially manufactured product [18, 25].

To eliminate or greatly reduce pollution, as well as to foresee and lessen the environmental repercussions of the manufacturing chain, green nanotechnology relies on the design and use of non-toxic nanomaterials [104, 204]. Other applications of green nanotechnology include photocatalysis, solar cells, fuel/bio-fuel cells, and cleaner production [78, 96, 168]. Furthermore, green nanotechnology applications include the conversion of diesel soot into carbon nanomaterials which can be used to recycle industrial wastes [30, 142]. In this chapter, we have elaborated the applications of green nanotechnology in different fields.

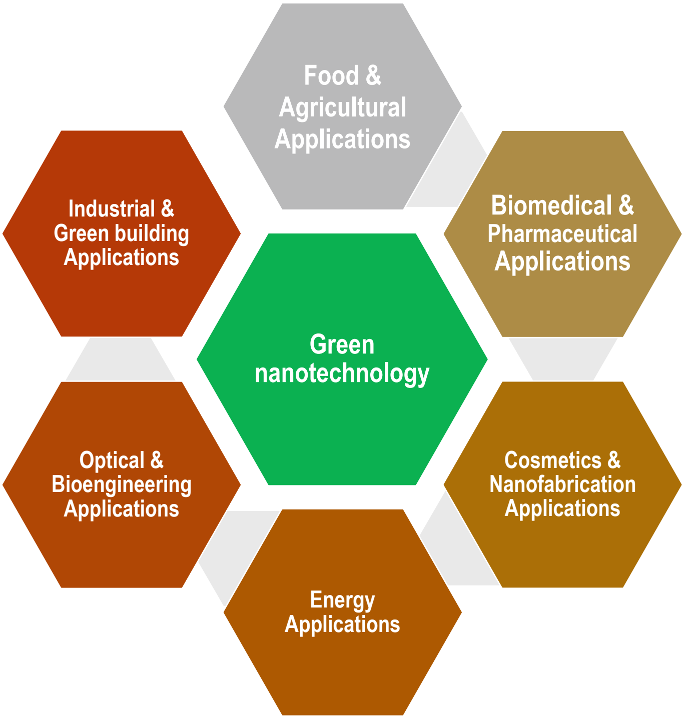

Fig. 3 Applications of green nanotechnology in various sectors

2 Green Nanotechnology and Its Applications

According to Anastas and Warner [11, 12] and Karn and Bergeson [112], green nanotechnology aims to develop and produce goods that are environmentally sustainable. Its primary objective is to inform readers about nanoparticles and their numerous useful and potentially harmful properties. Furthermore, negative impact on health and ecosystem can be reduced through nanotechnology, which has a wider societal benefit. Thus, green nanotechnology contributes from selection of raw materials to safer release to the environment [202].

2.1 Green Nanotechnology in Biomedical Applications

Treatment and prevention of many diseases could be revolutionized by biomedical nanotechnology [143]. Opportunities in the near future include the discovery of infectious microorganisms and viruses and the detection of molecules that are associated to the development of many diseases like cancer, diabetes, and neurological diseases. Nanoparticles with the ability to react to external stimuli would be useful in the delivery of cancer medications [7, 20, 47, 64, 88, 126, 134, 167, 174, 183]. In addition to medical implants, biomaterials can be used to create scaffolds for grafts. Non-specific macromolecules could be prevented from adhering to nanostructured surfaces created by this method. Biocompatibility of materials can be improved by controlling surface characteristics at the nanoscale.

There is currently a paucity of information on the pharmacological dangers linked with this technique, despite it is being widely available. Structures can take on entirely new features when scaled down to the nanoscale. A particle's aggressive or kidney-damaging actions appear to be best predicted by its minuscule size, which is mostly determined by its chemical composition. All medical technology applications (Fig. 4) must have a risk management plan in place. Afterward, we will take a look at some of the possible medical applications of nanomaterials and nanoparticles. Biocompatibility, implants, cardiology, cancer [42, 102, 158, 199], and theranostics are just a few of the many diagnostic and therapeutic uses for "nanorobots" and other forms of nanomedicine. Last but not least, the dangers to human health and ethical issues are discussed in detail [170, 171, 175].

In the field of drug delivery, nanomaterials and nanoparticles are useful tools. There are a number of nanomaterials that can be used to destroy cancer cells because of their unique mechanical, electrical, electronic, thermal, and optical properties [176, 202]. Due to their extraordinary size, optical and electrical capabilities, and comparatively low cost and ease of manufacturing, quantum dots have found utility in medical imaging applications. Physicochemical and biological properties of dendrimers can be enhanced through their small size (5 nm) and can pass via cell membranes, tissues,

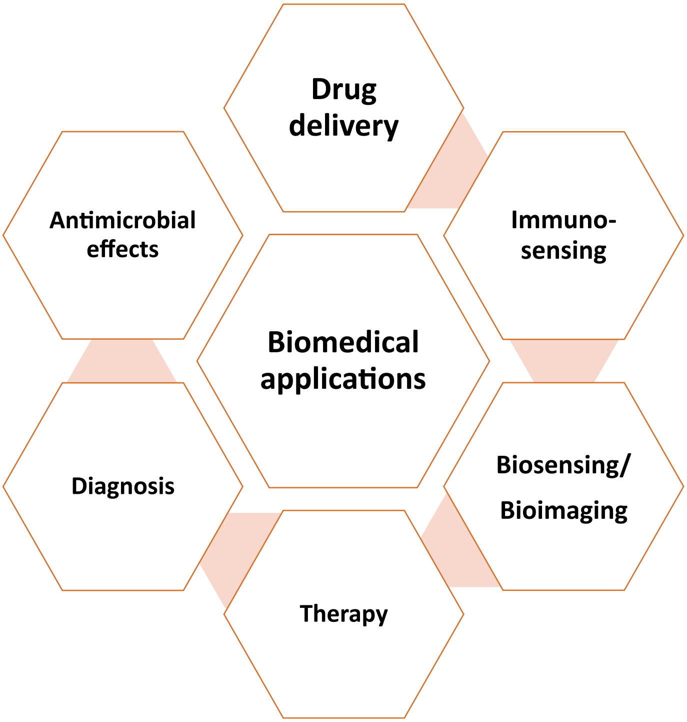

Fig. 4 Biomedical applications of green nanotechnology

and vascular pores. Nanomaterials can be used in protein, RNA, and DNA structure detection by using fluorescent markers for resonance imaging improvements [194, 202].

2.2 *Agricultural Applications of Green Nanotechnology*

The food and feed sectors have always relied on agriculture for supply and generation of raw materials. Population growth and the scarcity of natural resources (such as farmland and water) encourage agricultural development that is more profitable and environmentally friendly [109, 149, 236].

It is essential for the elimination of poverty and hunger that agricultural development takes place. As a result, we must take a risk in order to advance agricultural growth. This global mainstream has people living in poverty and in rural areas where agricultural expansion is less effective [166]. More recently, food and nutrition security have become a central part of cutting-edge scientific research. The objectives of agricultural development should include factors such as social inclusion, health, climate change, energy, ecosystem processes, natural resources, and good governance, [236]. As a result, sustainable agriculture increases the likelihood of eliminating poverty and hunger in the real world [213].

Incontrovertibly, the future of agriculture depends on the implementation of cutting-edge techniques like nanotechnology. In agricultural systems, the increasing use of smart nanotools has the potential for revolutionizing agricultural practices and reducing or eliminating their environmental impact [133, 189].

Nanotechnology plays a crucial role in sustainable agriculture by regulating nutrients and productivity via water quality [91, 149] and pesticide monitoring [165]. A general assessment of the health and environmental hazards posed by nanomaterials is impossible due to their wide range of properties and activities [165]. In agriculture, nanotechnology research also influences sustainable development. Soil fertility can be maintained, agricultural resources can be effectively managed, drugs can be effectively delivered, and this technology has proven to be effective. Risk assessments are continuing in several fields, including those dealing with biomass and agricultural wastes, food processing and packaging, and more [76]. It has recently become common practice to use nanosensors for environmental monitoring in agriculture because of their robustness and speed [106].

Microorganisms use nanoparticles to direct catalyze the destruction of toxic chemicals and waste products, making the process more effective. Hazardous compounds and toxins are broken down by organisms in agricultural soils and waters. Bioremediation (using beneficial microorganisms), phytoremediation (using plants), and mycoremediation are other commonly used terms (fungi and mushrooms). As a result, bioremediation can be used to safely and effectively remove heavy metals from soil and water using microorganisms [60]. As a result, agricultural bioremediation encourages long-term approaches to remediation that restore soil to its natural state. Consider using the nano–nano interaction to improve agricultural soil sustainability by removing potentially harmful components [60, 106]. Microbes are undeniably important in sustaining soil health, the environment, and agricultural productivity [145]. As a result, the introduction of modified NPs (chemical or green) should constantly be evaluated on a regular basis to ensure environmental stewardship in the agricultural sector (Fig. 5).

Although nanofertilizers (Table 1) have been widely available on the market in the past decade, the majority of agricultural fertilizers have not been developed by major chemical companies. Several types of nanofertilizers are available, including “nanozinc, silica, iron, titanium dioxide, core–shell quantum dots, and gold nanorods.” Its quality is further enhanced by the fact that it was released under strict supervision. Over the past decade, researchers [59, 239] have focused on the potential benefits of using metal oxide nanoparticles in agriculture. As a result of zinc deficiency in alkaline soils, agricultural productivity has been limited [180].

In the near future, nanomaterials will be used to protect crops and produce food. In agricultural fields, NPs play a crucial role in controlling insect pests and host pathogens [121]. The development of a novel nanoencapsulated pesticide formulation with slow release properties has been reported recently [29]. Increasing the effectiveness of active ingredients by preventing their premature degradation for longer periods of time is the primary way to achieve crop protection due to the development

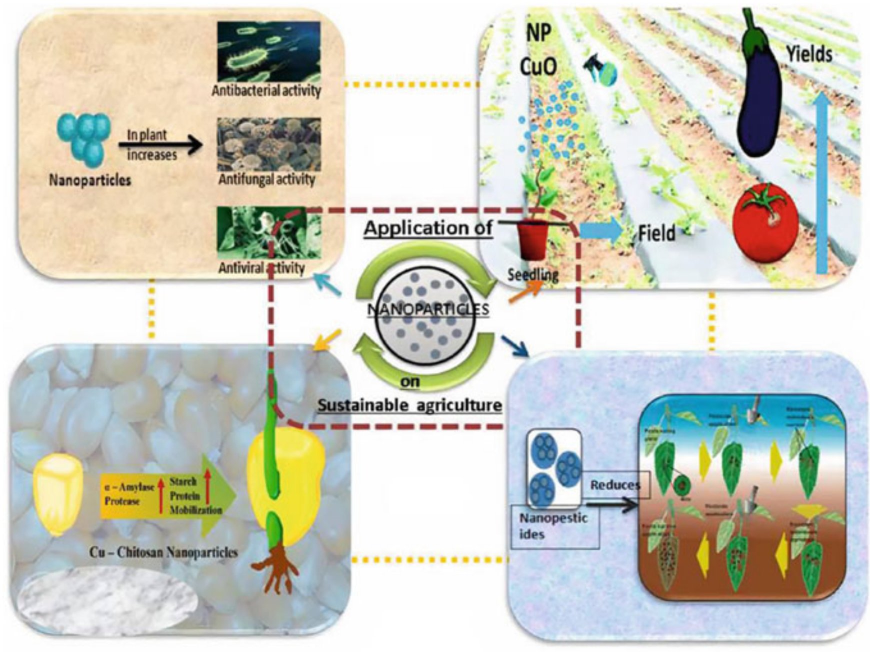

Fig. 5 Applications of green nanotechnology on sustainable agriculture [166]

Table 1 List of nanofertilizers and their composition [166]

Nanofertilizers	Composition
Nano-Gro™	Plant growth regulator and immunity enhancer
Nano-green	Extracts of corn, grain, soybeans, potatoes, coconut, and palm
Nano-Ag Answer	Microorganism, sea kelp, and mineral electrolyte
Biozar nanofertilizer	Combination of organic materials, micronutrients, and macromolecules
Nano max NPK fertilizer	Multiple organic acids chelated with major nutrients, amino acids, organic carbon, organic micro nutrients/trace elements, vitamins, and probiotic
Master nano chitosan organic fertilizer	Water soluble liquid chitosan, organic acid and salicylic acids, phenolic compounds
TAG NANO (NPK, PhoS, Zinc, Cal, etc.) fertilizers	Proteino-lacto-gluconate chelated with micronutrients, vitamins, probiotics, seaweed extracts, humic acid

of environmentally friendly nanoencapsulated insecticides [160], which has resulted in a decrease in pesticide doses and human exposure. There is a growing interest in developing non-toxic and environmentally friendly pesticide delivery systems in order to improve global food production and minimize the adverse effects on the environment [29, 55, 90, 110].

The quality of chemicals delivered to biological processes can be improved using nanoencapsulation, which is similar to microencapsulation. Nanoscale pesticides have recently been marketed as "microencapsulated pesticides" by some chemical companies [89]. Microencapsulated pesticides from Syngenta (Switzerland), "Subdew MAXX Karate ZEON, Ospreay' Chyella, Penncap-M, and BASF" are all suitable for use at the nanometer scale. "Primo MAXX, Banner MAXX, and Subdue MAXX" are all Syngenta products sold in Australia. These are nanoscale emulsions, despite the fact that they are commonly referred to as microemulsions in the marketplace. As a result, the distinction between microemulsion and nanoemulsion is kept as thin as possible. Agrochemicals and organic NPs are commonly formulated using this method [89].

Biosensor development will continue to be influenced by nanotechnology because of its many advantages. The unique properties of nanomaterials can greatly enhance the performance and sensitivity of biosensors [77], but it has also prompted the development of numerous new transduction technologies [190]. Utilizing nanomaterials streamlines the development of numerous (bio)sensors, including nanosensors and other nanosystems essential for biochemical analysis [77, 190, 221]. Mycotoxins, which are present in many different foods, can be detected fast and easily with (bio)sensors help [190].

2.3 Green Nanotechnology in Food Industry

Future food production will be significantly affected by nanotechnology. Food additives and food packaging are the primary uses of nanoparticles in the food industry. The most important differences between the two types of packaging are that additives can be used to enhance the flavor or texture of food, while packaging can help to prevent rotting and increase the quality of the product by minimizing gas flow during packaging [157].

Antimicrobial food contact surfaces, including containers, cutting boards, and freezers, are now being manufactured commercially using nanotechnology [210]. Sugars and proteins serve as a target recognition group for nanostructures used in food biosensors [38]. Foodborne pathogens and other contaminants can be detected and tracked using these biosensors. Environmentally protective encapsulation systems can benefit from nanotechnology as well. As a flavor and an antioxidant, it can be used in the formulation of food products as well [105]. While reducing the concentration of these substances, the goal is to increase their activity and efficiency [95]. Nutraceutical delivery systems and controlled release mechanisms are increasingly being investigated as the practice of adding new ingredients to foods [135]. All food production and processing could benefit from nanotechnology, but many of the techniques are prohibitively expensive or impossible to put into practice commercially. New functional materials and food formulations, as well as micro and nanoscale processing, product development, and storage development, are all areas in the food industry that can benefit from nanoscale techniques [156].

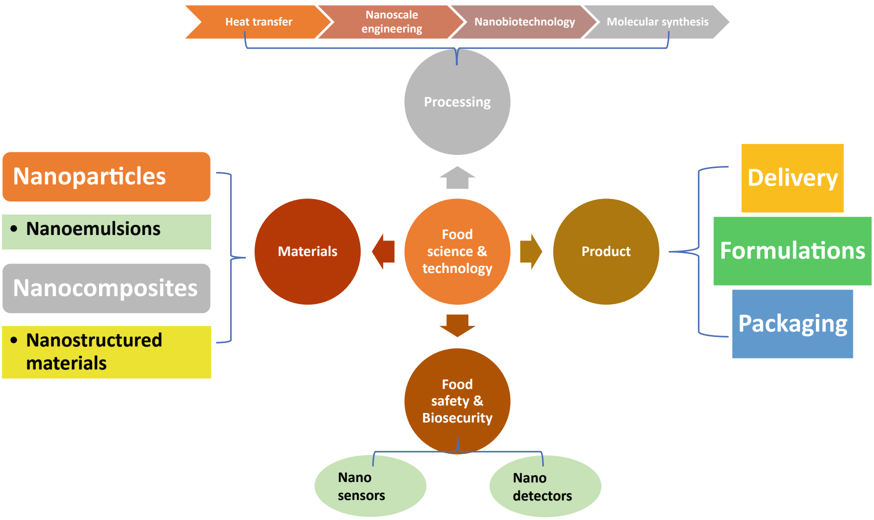

Fig. 6 Applications of green nanotechnology in food processing and technology [171]

A reduction in the risk of certain diseases, such as cancer, may be one of the physiological benefits of bioactive chemicals present in some foods. In the gastrointestinal system, nanotechnology is capable of improving transport characteristics, solubility, and long-term absorption by reducing particle size [41]. Ingredients like "omega-3 and omega-6 fatty acids, probiotics, prebiotics, vitamins, and minerals" are used in food nanotechnology [223]. A number of nanoparticles have been developed to ensure the safety of food products, including "micelles, liposomes, nanoemulsions, biopolymeric nanoparticles, and cubosomes" [71, 131, 152, 232]. Nanotechnology's applications in the food industry are illustrated in Fig. 6.

As of today, most of the nanotechnology research is concentrated in the fields of electronics, medicine, and automation. The topic of nanoparticles being unintentionally or purposefully introduced into food is a common one when discussing nanotechnology and food [39, 177, 216, 219]. Risks and benefits of using nanoparticles are that very little is known about their bioaccumulation and toxicity [97].

There are numerous applications for the incorporation of nanoparticles into food contact materials. TiO_2 pigment nanoparticles remain UV absorbent after becoming transparent. The absorption of UV radiation must be minimized in transparent wraps, films, or plastic containers. By using nanoclays, gas diffusion can be reduced and shelf life can be extended.

Additionally, food preservation is critical to the food industry's success. When exposed to foodborne pathogens, nanosensors, such as a system composed of hundreds of fluorescent nanoparticles, can fluoresce in a various forms of colors, allowing in order to detect food spoilage. By using nanosensors, it is possible to detect pathogens in hours or minutes rather than days [28], given the vital necessity of time in food microbiology. In packaging materials, nanosensors can be used as “electronic tongues” or “noses,” detecting the compounds that are emitted when food is spoiled [82, 125]. Microfluidic nanosensors [17] can also be used to detect infections quickly and accurately in real time and with great sensitivity.

Devices with nanometer- to millimeter-scale moving parts, known as NEMS (nanoelectromechanical systems), are already being employed in the food analysis sector as development tools for food preservation technology. One of the numerous benefits of using micro and nanotechnologies (MNTs) in food technology is the ability to carry about instruments that respond quickly, are inexpensive, and can communicate intelligently at multiple frequency levels. MNTs are ideal for food safety and quality since they are able to identify and manage any contamination packing or storage conditions [34].

The food industry’s nanotechnology R&D is heavily focused on food packaging and regulation [31]. In spite of public concerns about nanotechnology, the food packaging industry continues to develop products utilizing this technology. According to Fletcher [75], the global market for food and beverage packaging nanotech products will reach $20.4 billion by 2010. Despite increased marketing, researchers have found success in the realm of food and food products by applying nanotechnology [39]. Due to concerns around prospective food labeling and consumer health, nanotechnology has not yet been applied to the realm of food. Researchers in the Netherlands have developed nanopackaging, which detects when food is going bad and releases a preservative to extend its shelf life. One of the most fascinating emerging trends in the food sector is the use of nanopackaging to both improve food safety and lengthen its shelf life. The world has already adopted other, less dramatic (but more useful) innovations in nanopackaging [17, 32, 33].

2.4 Green Nanotechnology in Environmental Applications

Nanomaterials have been utilized to clean contaminated water, which includes heavy metal ions, organic and inorganic solvents, and a wide range of microorganisms [14, 123]. The affinity of nanomaterials for non-degradable pollutants has led to the development of nanomaterials for environmental cleanup and site remediation. Adopting eco-friendly building principles can reduce or eliminate environmental pollutants [8]. All forms of water contamination can be effectively removed by using nano-adsorbents such as “clay, zeolites, metals, metal oxides, polymeric membranes, porous nanofibers, and zero-valent iron” [188, 224]. As part of their irradiation-based degrading and mineralizing process, AOPs rely on semiconductor-based photocatalysts (natural and artificial) that are ecologically safe [215].

Nano-treatment reduces the amount of pollutants in the environment compared to earlier cleanup procedures [22]. Health and environmental problems can be prevented, reduced, and mitigated using nanotechnology [99]. As nanotechnology advances in environmental protection technologies, new solutions will be available to manage and remove pollutants in the atmosphere, groundwater supply, and surface water. Traditional techniques of cleansing will also benefit from this advancement [193].

In situ treatment with nanotechnology is a time and money-saving alternative to traditional methods [58]. Treatment of polluted areas with nano-based remediation technology can cut costs, speed cleaning, and virtually remove the need to dispose of or treat contaminated soils [85, 86]. Advanced research and development are looking into the possibility of using nanomaterials to efficiently filter out environmentally harmful contaminants [203, 237]. Recently, many nanomaterials, such as "nanoscale zeolites, metal–metal oxides, carbon nanotubes, dendrimers, and metal-polymer doped nanoparticles," have been studied for potential applications in nanotechnology [22, 161]. Nanomaterial oxides used on site, in addition to surface and groundwater cleanup, are effective for cleaning up non-aqueous phase fluid (NAPL) spills from subterranean oil tanks [50, 65, 94, 179].

Environmentally friendly products and processes can be developed using nanotechnology, which is central to green nanotechnology [62]. According to Maksimovic and Omanovic-Miklicanin [140], these technologies are primarily designed to be environmentally friendly and have a minimal impact on human health and the environment. Wastewater treatment using catalysts, adsorbents, and membranes based on nanotechnology is more environmentally friendly [214]. A high surface-to-volume ratio (SVR) makes nanoparticles promising for use in environmental purification and restoration [57]. Many researchers are working to create novel nanomaterials with enhanced selectivity, efficiency, and effectiveness for use in wastewater treatment. Nanotechnology for water treatment is the key to ensuring the safety and cleanliness of water supplies worldwide. Table 2 summarizes the nanotechnology applications which can be used to treat wastewater.

Nanotechnology-based remediation techniques are safer, more cost-effective, and more effective than conventional methods. Pollutant sensing and detection, cleaning,

Table 2 Applications of green nanotechnology in soil and water treatment [119]

Nanomaterials	Properties	Applications
Metal and metal oxides	Photocatalytic	Largely used for environmental remediation
	Nontoxic	Slurry reactors
	Green chemistry-based	Heavy metal, dyes, industrial effluent treatment
Adsorbents	Higher surface area	Removal of heavy metals
	Higher SVR	Dyes
	Higher adsorption rates	Pesticide degradation
	Easy to modify	Removal of organic pollutants, bacteria
Membrane and processes	Reliable	Treatment of water and wastewater
	Most trusted	Purification
	Widely used	Desalination
	Automated process	All fields of water and wastewater treatment

and pollution control are all potential applications for nanomaterials [115]. The nanomaterial's high SVR makes them ideal for water treatment and purification. Semiconductor nanomaterials are layered on top of conventional membrane treatments for purification and to create unique photocatalytic membranes [122]. Nanofiltration, photocatalytic processes, and adsorption are some of the methods used to solve wastewater treatment problems [13, 182].

Nanoparticles, nanomembranes, and other nanomaterials can be used for the detection and removal of a wide variety of chemical and biological pollutants [2, 9, 118, 120, 154]. Both filtration and photocatalysis can be accomplished with the use of membrane processes and nano-based materials [3, 141]. The use of environmentally friendly wastewater treatment solutions has become increasingly important due to sustainability concerns. Through the use of green chemistry to synthesize nanomaterials for environmental cleanup, hazardous waste generation can be reduced and toxic end products eliminated.

2.5 Green Nanotechnology in Renewable Energy Generation

The primary focus of this research is to develop green chemistry-based nano-enabled solar cells. Solar-absorbing polymers such as quantum dots, titanium dioxide, and cadmium telluride (CdT) are among them [92]. Compared to existing solar cells, these nano-based solar cells are much more cost-effective [222]. The effectiveness of solar cells is being improved by a number of efforts in this area. For the design of environmentally friendly products in the future, other techniques such as the deposition of nano-crystals, the use of nanowires, and the development of a very durable lamination layer that covers solar cells are also being investigated [150]. Energy storage devices for renewable energy have also been developed using nanotechnology research. The performance and cost benefits of solar devices based on nanotechnology are significant [212].

2.6 Green Nanotechnology in Green Building Constructions

Nanotechnology is an important technology in the field of green manufacturing as it has the potential to contribute to environmental sustainability. The services provided by green building professionals, engineers, and architects are directly affected by the innovations [51, 52]. Due to advances in nanotechnology, suitable materials with unique properties are now available. In the past, designers had to rely on a limited number of standard materials. The design and construction of buildings will be directly affected by nanotechnology due to its impact on information technology, sustainability, and the development of novel materials and uses [129]. The value chain established by nanotechnology in building design and construction is depicted in Fig. 7. This value chain was developed using a comprehensive strategy and deep

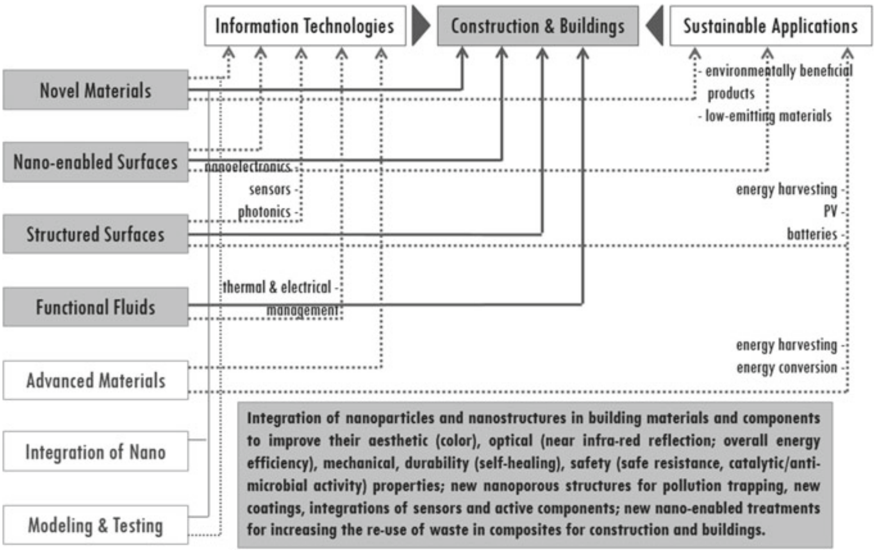

Fig. 7 Value chain created by nanotechnologies [51]

integration of state-of-the-art technologies via nanotechnology in green building design. Considerations of aesthetics, utility or functional performance, life-cycle cost, and sustainability from the user's point of view are at the heart of the most realistic and practical applications of nanotechnology [53].

All aspects of the project, material or product, and service must be questioned in a green building project. Teams working on buildings are urged to employ life-cycle thinking when calculating the environmental implications of the structure as a whole, rather than just its components. "Life-cycle assessment (LCA) and life-cycle costing (LCC)" are two methods used to determine total cost of ownership (TCO). Fuel, installation, operation, maintenance, disposal, financing, and replacement are all parts of LCC, which is used to evaluate each proposed technology and method for the project's environmental and economic viability [46].

As part of the green building lifecycle, it is essential to maximize the use of materials and energy. Green building design ideally has a fully closed-loop lifecycle. The objective is to minimize garbage leftover after a product has served its useful purpose. To ensure long-term viability, the material must be durable [54]. To last, a material must be structurally and aesthetically strong. There are various many advantages to designing for disassembly. It helps to increase the life of building components and systems, making them easier to repair or modernize. It also helps in recycling construction materials and rebuilding entire parts. Conventional energy sources such as "coal, oil and gas" have limited supplies and emit greenhouse gases into the atmosphere. "To improve our quality of life while preserving the planet's ability to support us, we must transition to renewable energy and design for energy efficiency." Reducing dependence on finite fossil fuel supplies and avoiding the effects of air pollution and climate change are just two of the environmental and social benefits of renewable energy [54].

Eco-friendly buildings are more efficient than buildings that are not. Environmentally friendly management refers to an organization that aims to reduce costs and improve operational efficiency by implementing sustainable practices in its buildings. The total cost of the facility is explained as follows: Only 10% of the time is spent on the building; 90% of the time is spent on building operating and maintaining the facility. Clearly, a great way to reduce costs and increase revenue is to have tight control over facility operating costs. A large portion of the company's budget is paid for fuel and other necessities. The organization/company can only achieve sustainability if it provides a work environment free of harmful air, chemicals, and materials [225].

Nanotechnology has the potential to greatly improve sustainability in a variety of ways, including material and energy efficiency, process efficiency, and productivity. Titanium dioxide (TiO_2) nanoparticles are being tested, for instance, by scientists in Hong Kong and Japan as a means of reducing air pollution [54]. Up to 90% of nitrogen oxides were removed in the experiments, suggesting that dusty cities could face major health risks by embedding these nanoparticles in roads and structures. TiO_2 is also used by the Japanese company Toto as a coating for the manufacture of tiles. Indoor air quality can be improved with the use of certain nanomaterials. This is possible by coating the concrete with a thin layer of TiO_2 nanoparticles that consume pollution. This catalytic action degrades pollutants in contact with the surface [54].

Surface applications add new functionality to the texture of new materials, improving the quality of structures. Many companies are experimenting with nanotechnology to improve the properties of various materials. Currently, materials and coatings improve the health and safety of buildings and homes, as well as increase their energy efficiency by storing the sun's rays for later use. Nanomaterials are also used in air quality monitoring, air filtration, and energy-efficient air-conditioning systems [54].

2.7 Green Nanotechnology in Coating Industry Applications

Coating technology is widely used in many areas of our daily lives. Coating materials are manufactured for a variety of purposes, from food and pharmaceuticals to wearable and consumer goods, industry and machinery, and auto and construction components [84]. A film of coating material is often applied to the surface or bulk material of an object to protect, enhance, or provide additional capabilities and properties. This can be achieved by using coating technologies that help to protect surfaces from degradation caused by exposure to environmental factors such as moisture, UV rays, as well as preventing or reducing fouling and biofouling [241]. They can reduce chemical and structural degradation as well as wear and tear. Antimicrobial properties used for self-cleaning properties, such as super-hydrophobicity or super-hydrophilicity, are added to surfaces by coating methods [84]. Also, in food and medicine, functional coatings can be used to mask taste and smell, protect and stabilize the physical environment, and release specific amounts into the body. As a result of the strong demand for functional coating materials and technologies resulting in economic value, more time and effort are devoted to research and development [241].

Functional coating technology mainly focuses on the development of coating materials and deposition processes for various applications. Inorganic nanoparticles and organic polymers can be used as functional coating materials based on their specific properties and functions [81]. There has been a meteoric rise in the creation of novel nanotechnology-based coatings in the last few years.

Nanotechnology has led to new advances in coated materials such as antifouling, anti-reflective, and fire-retardant coatings [101, 138, 227] (Fig. 8). Several silicone resin polymer foam composites have been used, including "silicone resin polymer foam composites [226], polydimethylsiloxane/graphene foam nanocomposites [35], water-based clay/graphene oxide nanoribbon networks [234] and composites of graphene oxide and melamine sponge" [36]. Tang's team created several types of fire-proof coatings and alarm coatings based on the GO Network [37, 229]. However, Lejars et al. [128], Banerjee et al. [19], and Detty et al. [56] provide in-depth studies of the use of sol–gel technology to antifouling coatings, surface design, and alterations to thwart biofouling growth. Raut et al. [169] summarizes anti-reflective coatings made of silicon and TiO_2, functionalized polymers, and gallium as well as their production methods. Coating materials can benefit from the introduction of nanotechnology, which provides new features and functionalities that can be used to improve the performance of coating materials.

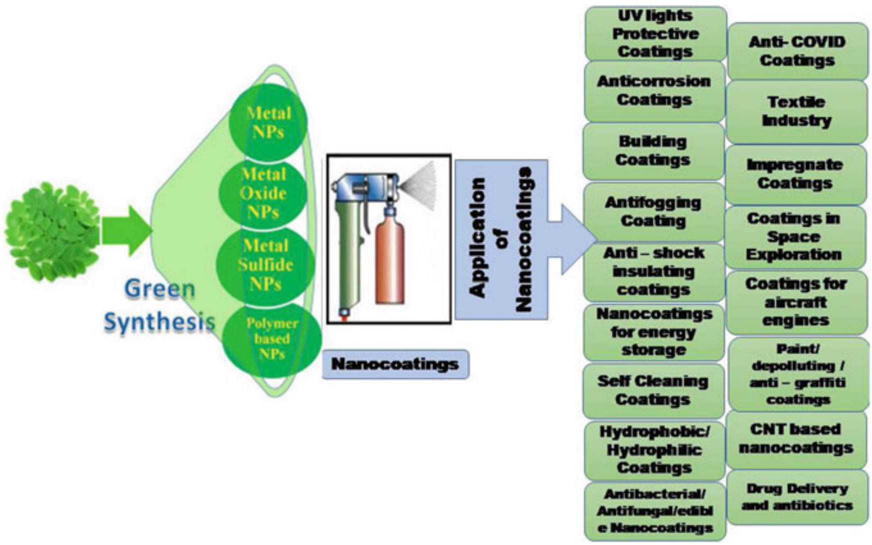

Fig. 8 Green nanotechnology in coating applications [84]

Generally, functional coating materials based on nano-composite chemistry are synthesized and then applied to surfaces [24, 151, 243]. Instead, deposition techniques are used to create or change the surface structures of coating materials at the nanometer level. There are several methods of coating application, including spraying and drop-casting, as well as dip coating and cast coating [15, 73, 93, 116].

In contrast, functional coatings play a crucial role in green construction. The most common type of coating is undoubtedly paint, which provides a variety of benefits including aesthetics and solar reflection [201, 209]. Other functional coatings such as self-cleaning, solar filtering, light and temperature control can be applied to external aspects of structures such as walls, ceilings, and windows [209].

Using nanotechnology for green building design and construction to improve properties and performance. Some examples are photocatalytic coatings, coatings that reduce surface solar radiation, and PCM coatings. These functional coatings are being developed by researchers around the world to reduce the carbon footprint of green building components. As a result of the self-cleaning and anti-icing capabilities of superhydrophobic coatings applied to building exteriors or civil engineering materials, additional resources and efforts are not required to successively clean, defrost, or repair worn or torn and cracked building components [228]. In addition, they contribute to the breathability of the wall, reduce thermal conductivity, and improve the resilience of the wall to biological agents such as bacteria [238]. As a result of the large surface area covered by water and the photocatalytic degradation of dirt and impurities under sunlight, the self-cleaning property reduces the effort and resources required for cleaning [159]. The anti-microbial [130] and moisture-controlling properties [61] of the hydrophilic coating have also been described. Solar reduction coatings, on the other hand, limit heat absorbed from the sun by using less energy to maintain a comfortable temperature inside the building [240]. Effectively reducing the temperature inside a building using phase change material coatings is a great way to save money on energy costs [111].

2.8 Green Nanotechnology in Cosmetic Applications

As defined by the Food and Drug Administration (FDA), cosmetic products are products designed "to enhance, promote, or alter the human body or any part thereof". A cosmetic is any item used to enhance the skin's natural beauty and cleanliness [83]. The worldwide demand for cosmetics has climbed by 4.5% each year in the twenty-first century, with yearly growth rates ranging from 3.0 to 5.5% [67, 181].

In the cosmetics industry, a product is considered to be "cosmetic" if it contains physiologically active substances that have a therapeutic impact on people [67, 136, 181]. Cosmetics possess bioactive components with quantifiable therapeutic properties that make them an excellent choice between pharmaceuticals and cosmetics. These ingredients are useful for treating a wide variety of issues, such as skin aging, hair loss, dryness, pigmentation, dark spots [114, 136] (Fig. 9).

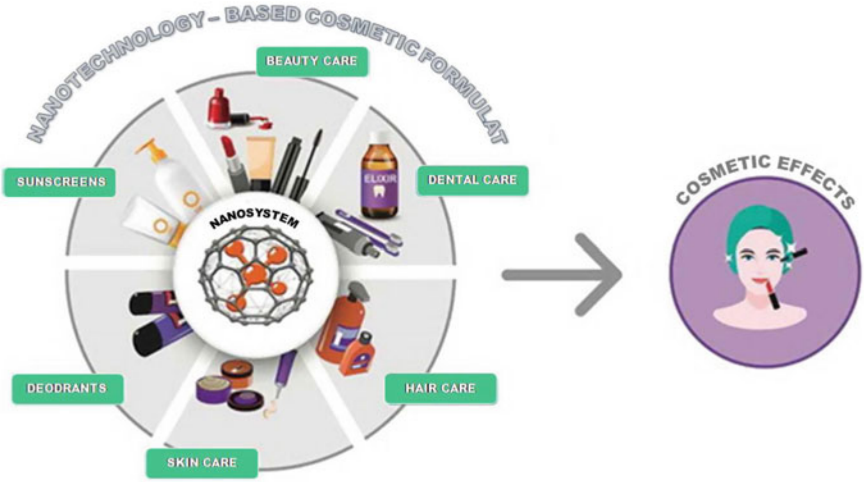

Fig. 9 Green nanotechnology in cosmetic applications [185]

As one of the most promising new technologies of the twenty-first century, nanotechnology is closely monitored by the cosmetics industry. It is possible to improve the delivery of bioactive chemicals with the use of nanotechnology in nanocosmeceutical formulations [100, 114]. Nanoparticles of cosmetic compounds can be prepared using this technology, which results in increased production efficiency and better skin damage repair due to the compounds' smaller size and higher absorption rate [197].

It has been shown that various types of nanoparticles can be used to enhance cosmetics, including "liposomes [206], niosomes [231], solid lipid nanoparticles [208], nanocapsules [178], micelles [235], dendrimers [147] and metal nanoparticles [137]." This process allows us to develop fragrances with extended longevity, cosmetics with enhanced UV protection, and effective anti-aging remedies (Fig. 9). The use of nanocarriers can reduce the size of bioactive ingredients in cosmetics, increasing their therapeutic potential [136].

The use of micellar nanoparticles in skin washing products is widely regarded as one of the most significant and cutting-edge breakthroughs in the field of cosmetics based on nanotechnology [40, 66, 79, 146]. Using nanotechnology, lipophilic bioactive ingredients can be incorporated into cosmetic formulations that possess a variety of physical and chemical properties. Nanoparticle size, encapsulation efficiency, and fabrication cost of micellar nanotechnology are superior to liposomes and niosomes [127, 207]. Many global and local cosmetics companies use micellar nanotechnology in their cleanser formulations to claim that their micellar nanotechnology-infused facial cleanser is the most effective on the market. With micellar nanotechnology, these brands have performed well. These cosmetics can benefit from using this process.

2.9 Green Nanotechnology in Textile Industry Applications

The textile industry is a leading user of nanotechnology, and numerous nanotextiles—including a wide range of consumer goods that employ nanoparticles—are currently on the market [1, 48, 68, 108, 113, 173, 187, 233]. Some of these high-tech textiles have built-in safety characteristics like being resistant to fire, dirt, water, and even ultraviolet light [4, 69, 70, 230]. The possibilities for textile applications are being broadened by the use of nanocoatings and nanofinishings [21, 74, 87, 107, 162]. High-performance textile coatings made from different nanomaterials can help a lot [23, 139, 172, 191, 196, 218]. Recent research on textile modification and characterization has focused on plasma and nano-pretreatment [200]. Fabrics created with nanotechnology are displayed in Fig. 10. Nanomaterials are able to offer greater functionality in textiles, despite their small size and large surface area. Commonly used carbon-based nanomaterials in textiles include "metal oxides, metal and nanoclay nanoparticles, core–shell nanoparticles, composite nanomaterials, hybrid nanomaterials, and polymeric nanomaterials such as graphene, carbon nanofibers, and carbon nanotubes."

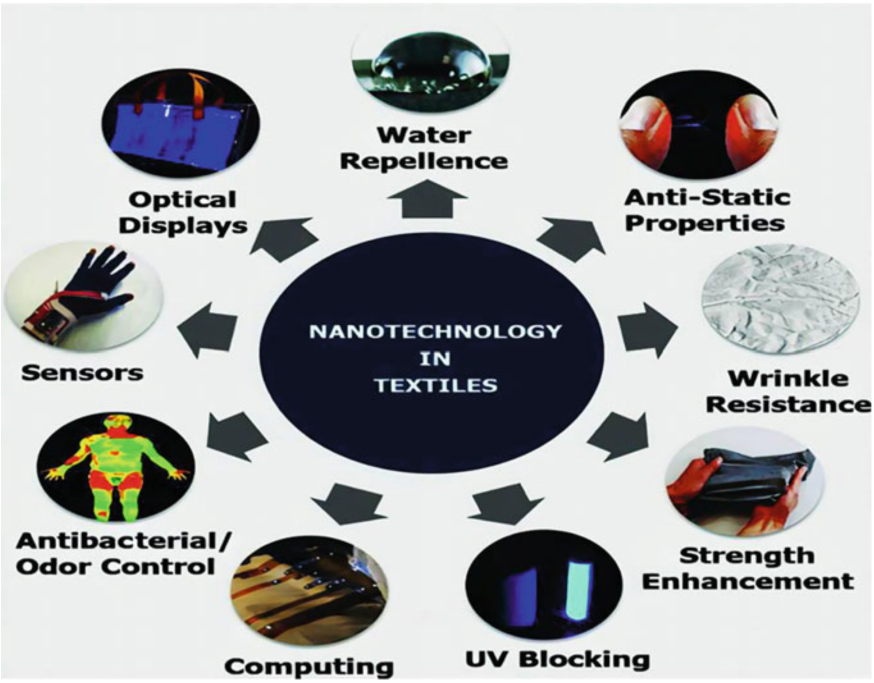

Fig. 10 Applications of nanotechnology in textiles [184]

3 Limitations of Green Nanotechnology

A new field of study, green nanotechnology, has its limits and limitations to overcome. The ACS Green Chemistry Institute (ACS GCI) reports on the main problems of green nanotechnology: Managing issues related to the toxicity of nanomaterials must also overcome economic and technical challenges. (1) Nanomanufacturing processes are subjected to regulatory procedures, (2) implementation of scale-up methods, (3) cycle of life aspects.

Green and sustainable development must take into account all of the above factors. Although green nanotechnology can reduce pollution and improve the environment, the expense and dangers of nano-based product manufacture are important limits. However, even if green nanotechnology has made progress, the level of sustainability has always been a challenge. However, upstream processing of green nanotechnology-based materials remains an important concern [44].

Green nanoproducts are now being investigated for their synthesis and application, although very few products have been developed in the commercial market so far [45]. The consensus is that the commercial potential of green nanotechnology is expected to be fully understood within a few years.

4 Conclusions

Using nanotechnology, we can solve the world's most serious issues. The term green nanotechnology refers to a technology that has a green advantage, as its name implies. Green chemistry is being thought about more and more in the context of nanotechnology because it provides a framework. Many benefits have been found through the studies, but some drawbacks and issues also need to be addressed. By using green nanotechnology, we can help solve the environmental crisis and promote sustainable development. For nanotechnology to be environmentally sustainable, life-cycle considerations must be included in the analysis of nanoproducts. New nanoproducts created through the nano-manufacturing process undergo life-cycle assessments before being released into commerce to fully assess their potential contribution to green development. However, there is always opportunity for development in bringing green chemistry ideas to nanotechnology.

References

1. Abdullaeva Z (2017) Nanomaterials for clothing and textile products. In: Nanomaterials in daily life. Springer, Cham, pp 111–132
2. Adeleye AS, Conway JR, Garner K, Huang Y, Su Y, Keller AA (2016) Engineered nanomaterials for water treatment and remediation: costs, benefits, and applicability. Chem Eng J 286:640–662

3. Adriano DC, Wenzel WW, Vangronsveld J, Bolan NS (2004) Role of assisted natural remediation in environmental cleanup. Geoderma 122(2–4):121–142
4. Afzali A, Maghsoodlou S, Ciocoiu M, Maamir S (2016) Engineering nanotextiles: design of textile products. In: Nanostructured polymer blends and composites in textiles, pp 1–40
5. Ahmed S, Ahmad M, Swami BL, Ikram S (2016) A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: a green expertise. J Adv Res 7(1):17–28
6. Akhtar MS, Panwar J, Yun YS (2013) Biogenic synthesis of metallic nanoparticles by plant extracts. ACS Sustain Chem Eng 1(6):591–602
7. Allen TM (2002) Ligand-targeted therapeutics in anticancer therapy. Nat Rev Cancer 2(10):750–763
8. Allen DT, Shonnard DR (2001) Green engineering: environmentally conscious design of chemical processes. Pearson Education
9. Alqadami AA, Naushad M, Abdalla MA, Ahamad T, Alothman ZA, Alshehri SM (2016) Synthesis and characterization of Fe3O4@ TSC nanocomposite: highly efficient removal of toxic metal ions from aqueous medium. RSC Adv 6(27):22679–22689
10. Anandan M, Poorani G, Boomi P, Varunkumar K, Anand K, Chuturgoon AA, Saravanan M, Prabu HG (2019) Green synthesis of anisotropic silver nanoparticles from the aqueous leaf extract of *Dodonaea viscosa* with their antibacterial and anticancer activities. Process Biochem 80:80–88
11. Anastas PT, Warner JC (1998a) Green: chemistry. In: Frontiers. Oxford University Press, New York
12. Anastas PT, Warner JC (1998) Principles of green chemistry. Green chemistry: theory and practice. Oxford University Press, New York, p 29
13. Andreescu S, Njagi J, Ispas C, Ravalli MT (2009) JEM spotlight: applications of advanced nanomaterials for environmental monitoring. J Environ Monit 11(1):27–40
14. Awual MR, Eldesoky GE, Yaita T, Naushad M, Shiwaku H, AlOthman ZA, Suzuki S (2015) Schiff based ligand containing nano-composite adsorbent for optical copper (II) ions removal from aqueous solutions. Chem Eng J 279:639–647
15. Aziz F, Ismail AF (2015) Spray coating methods for polymer solar cells fabrication: a review. Mater Sci Semicond Process 39:416–425
16. Aziz N, Faraz M, Pandey R, Shakir M, Fatma T, Varma A, Barman I, Prasad R (2015) Facile algae-derived route to biogenic silver nanoparticles: synthesis, antibacterial, and photocatalytic properties. Langmuir 31(42):11605–11612
17. Baeumner A (2004) Nanosensors identify pathogens in food. Food Technol (Chicago) 58(8):51–55
18. Balbus JM, Florini K, Denison RA, Walsh SA (2007) Protecting workers and the environment: an environmental NGO's perspective on nanotechnology. J Nanopart Res 9(1):11–22
19. Banerjee I, Pangule RC, Kane RS (2011) Antifouling coatings: recent developments in the design of surfaces that prevent fouling by proteins, bacteria, and marine organisms. Adv Mater 23(6):690–718
20. Banerjee AN (2018) Graphene and its derivatives as biomedical materials: future prospects and challenges. Interface Focus 8(3):20170056
21. Banerjee B (2019) Rubber nanocomposites and nanotextiles: perspectives in automobile technologies. Walter de Gruyter GmbH & Co KG
22. Bardos P, Bone B, Černík M, Elliott DW, Jones S, Merly C (2015) Nanoremediation and international environmental restoration markets. Remediat J 25(2):83–94
23. Bashari A, Shakeri M, Shirvan AR, Najafabadi SA (2018) Functional finishing of textiles via nanomaterials. In: Nanomaterials in the wet processing of textiles, pp 1–70
24. Bassiri-Gharb N, Bastani Y, Bernal A (2014) Chemical solution growth of ferroelectric oxide thin films and nanostructures. Chem Soc Rev 43(7):2125–2140
25. Benn TM, Westerhoff P (2008) Nanoparticle silver released into water from commercially available sock fabrics. Environ Sci Technol 42(11):4133–4139
26. Berti L, Burley GA (2008) Nucleic acid and nucleotide-mediated synthesis of inorganic nanoparticles. Nat Nanotechnol 3(2):81–87

27. Bhainsa KC, D'souza SF (2006) Extracellular biosynthesis of silver nanoparticles using the fungus Aspergillus fumigatus. Colloids Surf, B 47(2):160–164
28. Bhattacharya S, Jang J, Yang L, Akin D, Bashir R (2007) BioMEMS and nanotechnology-based approaches for rapid detection of biological entities. J Rapid Methods Autom Microbiol 15(1):1–32
29. Bhattacharyya A, Duraisamy P, Govindarajan M, Buhroo AA, Prasad R (2016) Nano-biofungicides: emerging trend in insect pest control. Adv Appl Through Fungal Nanobiotechnol 2016:307–319
30. Biju V, Itoh T, Anas A, Sujith A, Ishikawa M (2008) Semiconductor quantum dots and metal nanoparticles: syntheses, optical properties, and biological applications. Anal Bioanal Chem 391(7):2469–2495
31. Brody AL (2003) "Nano, nano" food packaging technology-packaging. Food Technol-Chicago 57(12):52–54
32. Brody AL (2006) Nano and food packaging technologies converge. Food Technol 60:92–94
33. Brody AL (2006) Food packaging climbs to the summit. Food Technol 60:73–75
34. Canel C (2006) Micro and nanotechnologies for food safety and quality applications. MNE 6:219–225
35. Cao CF, Wang PH, Zhang JW, Guo KY, Li Y, Xia QQ, Zhang GD, Zhao L, Chen H, Wang L, Gao JF (2020) One-step and green synthesis of lightweight, mechanically flexible and flame-retardant polydimethylsiloxane foam nanocomposites via surface-assembling ultralow content of graphene derivative. Chem Eng J 393:124724
36. Cao CF, Liu WJ, Xu H, Yu KX, Gong LX, Guo BF, Li YT, Feng XL, Lv LY, Pan HT, Zhao L (2021) Temperature-induced resistance transition behaviors of melamine sponge composites wrapped with different graphene oxide derivatives. J Mater Sci Technol 85:194–204
37. Cao CF, Yu B, Chen ZY, Qu YX, Li YT, Shi YQ, Ma ZW, Sun FN, Pan QH, Tang LC, Song P (2022) Fire intumescent, high-temperature resistant, mechanically flexible graphene oxide network for exceptional fire shielding and ultra-fast fire Warning. Nano-micro Lett 14(1):1–8
38. Charych D, Cheng Q, Reichert A, Kuziemko G, Stroh M, Nagy JO, Spevak W, Stevens RC (1996) A 'litmus test' for molecular recognition using artificial membranes. Chem Biol 3(2):113–120
39. Chau CF, Wu SH, Yen GC (2007) The development of regulations for food nanotechnology. Trends Food Sci Technol 18(5):269–280
40. Che Marzuki NH, Wahab RA, Abdul Hamid M (2019) An overview of nanoemulsion: concepts of development and cosmeceutical applications. Biotechnol Biotechnol Equip 33(1):779–797
41. Chen L, Remondetto GE, Subirade M (2006) Food protein-based materials as nutraceutical delivery systems. Trends Food Sci Technol 17(5):272–283
42. Cheng K, Sano M, Jenkins CH, Zhang G, Vernekohl D, Zhao W, Wei C, Zhang Y, Zhang Z, Liu Y, Cheng Z (2018) Synergistically enhancing the therapeutic effect of radiation therapy with radiation activatable and reactive oxygen species-releasing nanostructures. ACS Nano 12(5):4946–4958
43. Chithrani BD, Ghazani AA, Chan WC (2006) Determining the size and shape dependence of gold nanoparticle uptake into mammalian cells. Nano Lett 6(4):662–668
44. Clark JH (1999) Green chemistry: challenges and opportunities. Green Chem 1(1):1–8
45. Constable DJ, Curzons AD, Cunningham VL (2002) Metrics to 'green'chemistry-which are the best? Green Chem 4(6):521–527
46. Cottrell M (2014) Guide to the LEED Green Associate V4 exam. John Wiley & Sons, Inc., Hoboken, NJ
47. Daraee H, Pourhassanmoghadam M, Akbarzadeh A, Zarghami N, Rahmati-Yamchi M (2016) Gold nanoparticle–oligonucleotide conjugate to detect the sequence of lung cancer biomarker. Artif Cells Nanomed Biotechnol 44(6):1417–1423
48. Darwesh OM, Ali SS, Matter IA, Elsamahy T (2021) Nanotextiles waste management: controlling of release and remediation of wastes. In: Nanosensors and nanodevices for smart multifunctional textiles. Elsevier, pp 267–286

49. De Gusseme B, Sintubin L, Baert L, Thibo E, Hennebel T, Vermeulen G, Uyttendaele M, Verstraete W, Boon N (2010) Biogenic silver for disinfection of water contaminated with viruses. Appl Environ Microbiol 76(4):1082–1087
50. Deif AM (2011) A system model for green manufacturing. J Clean Prod 19(14):1553–1559
51. Demirdoven J (2012a) Nanotechnology enabling BIM for facility owners. In: Presentation for Ecobuild America 2012 conference, Washington, DC
52. Demirdoven J (2012b) Nanotechnology applications in construction. In: Presentation for CAEE seminar series. Illinois Institute of Technology, Chicago
53. Demirdoven J, Karacar P (2013) Nanotechnology applications enabling green buildings and their effects on architectural design. In: Proceedings of the eighth international Sinan symposium: awareness. Trakya University, Edirne
54. Demirdoven JB, Karacar P (2015) Green nanomaterials with examples of applications. In: GreenAge symposium. Mimar Sinan Fine Arts University Faculty of Architecture, Istanbul, Turkey
55. de Oliveira JL, Campos EV, Bakshi M, Abhilash PC, Fraceto LF (2014) Application of nanotechnology for the encapsulation of botanical insecticides for sustainable agriculture: prospects and promises. Biotechnol Adv 32(8):1550–1561
56. Detty MR, Ciriminna R, Bright FV, Pagliaro M (2014) Environmentally benign sol–gel antifouling and foul-releasing coatings. Acc Chem Res 47(2):678–687
57. Diallo M, Brinker CJ (2011) Nanotechnology for sustainability: environment, water, food, minerals, and climate. In: Nanotechnology research directions for societal needs in 2020. Springer, Dordrecht, pp 221–259
58. Diallo MS, Fromer NA, Jhon MS (2013) Nanotechnology for sustainable development: retrospective and outlook. Nanotechnology for sustainable development. Springer, Cham, pp 1–16
59. Dimkpa CO (2014) Can nanotechnology deliver the promised benefits without negatively impacting soil microbial life? J Basic Microbiol 54(9):889–904
60. Dixit R, Malaviya D, Pandiyan K, Singh UB, Sahu A, Shukla R, Singh BP, Rai JP, Sharma PK, Lade H, Paul D (2015) Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes. Sustainability 7(2):2189–2212
61. Dong C, Lu L (2019) Enhancing the dehumidification efficiency of solar-assisted liquid desiccant air dehumidifiers using nanoscale TiO2 super-hydrophilic coating. Energy Procedia 158:5765–5769
62. Dornfeld D, Yuan C, Diaz N, Zhang T, Vijayaraghavan A (2013) Introduction to green manufacturing. Green manufacturing. Springer, Boston, pp 1–23
63. dos Santos OA, Backx BP (2020) Green Nanotechnology: the influence of intermolecular and supramolecular interactions. J Nanotechnol Nanomater 1(3):104–108
64. Doubrovsky VA, Yanina IY, Tuchin VV (2011) Inhomogeneity of photo-induced fat cell lipolysis. In: Saratov fall meeting 2010: optical technologies in biophysics and medicine XII 2011, vol 7999. SPIE, pp 145–153
65. Dreher KL (2004) Health and environmental impact of nanotechnology: toxicological assessment of manufactured nanoparticles. Toxicol Sci 77(1):3–5
66. Duarah SA, Pujari KU, Durai RD, Narayanan VH (2016) Nanotechnology-based cosmeceuticals: a review. Int J Appl Pharm 8(1):8–12
67. Dureja H, Kaushik D, Gupta M, Kumar V, Lather V (2005) Cosmeceuticals: an emerging concept. Indian J Pharmacol 37(3):155
68. Ehrman A, Nguyen TA, Tri PN (2020) Nanosensors and nanodevices for smart multifunctional textiles. Elsevier
69. El-Naggar ME, Shaarawy S, Hebeish AA (2018) Multifunctional properties of cotton fabrics coated with in situ synthesis of zinc oxide nanoparticles capped with date seed extract. Carbohyd Polym 181:307–316
70. Elsayed EM, Attia NF, Alshehri LA (2020) Innovative flame retardant and antibacterial fabrics coating based on inorganic nanotubes. Chem Select 5(10):2961–2965

71. Esposito E, Cortesi R, Drechsler M, Paccamiccio L, Mariani P, Contado C, Stellin E, Menegatti E, Bonina F, Puglia C (2005) Cubosome dispersions as delivery systems for percutaneous administration of indomethacin. Pharm Res 22(12):2163–2173
72. Faccini M, Vaquero C, Amantia D (2012) Development of protective clothing against nanoparticle based on electrospun nanofibers. J Nanomater 2012:892894
73. Felton LA (2007) Characterization of coating systems. AAPS PharmSciTech 8(4):258–266
74. Ferraris M, Perero S, Miola M, Ferraris S, Gautier G, Maina G, Fucale G, Verne E (2010) Chemical, mechanical, and antibacterial properties of silver nanocluster–silica composite coatings obtained by sputtering. Adv Eng Mater 12(7):B276–B282
75. Fletcher A (2006) Nanotech food conference targets future opportunities. Available at www.foodproductiondaily.com
76. Floros JD, Newsome R, Fisher W, Barbosa-Cánovas GV, Chen H, Dunne CP, German JB, Hall RL, Heldman DR, Karwe MV, Knabel SJ (2010) Feeding the world today and tomorrow: the importance of food science and technology: an IFT scientific review. Comprehen Rev Food Sci Food Saf 9(5):572–599
77. Fraceto LF, Grillo R, de Medeiros GA, Scognamiglio V, Rea G, Bartolucci C (2016) Nanotechnology in agriculture: which innovation potential does it have? Front Environ Sci 2016:20
78. Fujihara K, Kumar A, Jose R, Ramakrishna S, Uchida S (2007) Spray deposition of electrospun TiO_2 nanorods for dye-sensitized solar cell. Nanotechnology 18(36):365709
79. Fukui H (2018) Development of new cosmetics based on nanoparticles. In: Nanoparticle technology handbook. Elsevier, pp 399–405
80. Gadkari RR, Ali SW, Joshi M, Rajendran S, Das A, Alagirusamy R (2020) Leveraging antibacterial efficacy of silver loaded chitosan nanoparticles on layer-by-layer self-assembled coated cotton fabric. Int J Biol Macromol 162:548–560
81. Gao N, Zhang Z, Deng J, Guo X, Cheng B, Hou H (2022) Acoustic metamaterials for noise reduction: a review. Adv Mater Technol 2022:2100698
82. García M, Aleixandre M, Gutiérrez J, Horrillo MC (2006) Electronic nose for wine discrimination. Sens Actuators, B Chem 113(2):911–916
83. Gautam A, Singh D, Vijayaraghavan R (2011) Dermal exposure of nanoparticles: an understanding. J Cell Tissue Res 11(1):2703–2708
84. Gautam YK, Sharma K, Tyagi S, Kumar A, Singh BP (2022) Applications of green nanomaterials in coatings. In: Green nanomaterials for industrial applications. Elsevier, pp 107–152
85. Gil-Díaz M, Diez-Pascual S, González A, Alonso J, Rodríguez-Valdés E, Gallego JR, Lobo MC (2016) A nanoremediation strategy for the recovery of an as-polluted soil. Chemosphere 149:137–145
86. Glavic P, Lukman R (2007) Review of sustainability terms and their definitions. J Clean Prod 15(18):1875–1885
87. Gokarneshan N, Chandrasekar PT, Suvitha L (2017) Advances in nanotextile finishes—an approach towards sustainability. Text Cloth Sustain 1–56
88. Gorner T, Gref R, Michenot D, Sommer F, Tran MN, Dellacherie E (1999) Lidocaine-loaded biodegradable nanospheres. I. Optimization of the drug incorporation into the polymer matrix. J Control Release 57(3):259–268
89. Gouin S (2004) Microencapsulation: industrial appraisal of existing technologies and trends. Trends Food Sci Technol 15(7–8):330–347
90. Grillo R, Abhilash PC, Fraceto LF (2016) Nanotechnology applied to bio-encapsulation of pesticides. J Nanosci Nanotechnol 16(1):1231–1234
91. Gruere GP (2012) Implications of nanotechnology growth in food and agriculture in OECD countries. Food Policy 37(2):191–198
92. Guo KW (2012) Green nanotechnology of trends in future energy: a review. Int J Energy Res 36(1):1–7
93. Habibi MH, Parhizkar J (2015) Cobalt ferrite nano-composite coated on glass by Doctor Blade method for photo-catalytic degradation of an azo textile dye reactive Red 4: XRD, FESEM and DRS investigations. Spectrochim Acta Part A Mol Biomol Spectrosc 150:879–885

94. Han C, Andersen J, Pillai SC, Fagan R, Falaras P, Byrne JA, Dunlop PS, Choi H, Jiang W, O'Shea K, Dionysiou DD (2013) Chapter green nanotechnology: development of nanomaterials for environmental and energy applications. In: Sustainable nanotechnology and the environment: advances and achievements. American Chemical Society, pp 201–229
95. Haruyama T (2003) Micro-and nanobiotechnology for biosensing cellular responses. Adv Drug Deliv Rev 55(3):393–401
96. Hashimoto K, Irie H, Fujishima A (2005) TiO_2 photocatalysis: a historical overview and future prospects. Jpn J Appl Phys 44(12R):8269
97. Helmut Kaiser Consultancy Group (HKCG) (2009) Study: nanotechnology in food and food processing industry worldwide, 2006–2010–2015. Helmut Kaiser Consultancy Group, Beijing
98. Hemmati S, Rashtiani A, Zangeneh MM, Mohammadi P, Zangeneh A, Veisi H (2019) Green synthesis and characterization of silver nanoparticles using Fritillaria flower extract and their antibacterial activity against some human pathogens. Polyhedron 158:8–14
99. Hood E (2004) Nanotechnology: looking as we leap. Environ Health Perspect 112(13):A740
100. Hougeir FG, Kircik L (2012) A review of delivery systems in cosmetics. Dermatol Ther 25(3):234–237
101. Huang H, Huang M, Zhang W, Pospisil S, Wu T (2020) Experimental investigation on rehabilitation of corroded RC columns with BSP and HPFL under combined loadings. J Struct Eng 146(8):04020157
102. Huff TB, Tong L, Zhao Y, Hansen MN, Cheng JX, Wei A (2007) Hyperthermic effects of gold nanorods on tumor cells. Nanomedicine 2:125–132
103. Hullmann A, Meyer M (2003) Publications and patents in nanotechnology. Scientometrics 58(3):507–527
104. Iavicoli I, Leso V, Ricciardi W, Hodson LL, Hoover MD (2014) Opportunities and challenges of nanotechnology in the green economy. Environ Health 13(1):1–11
105. Imafidon GI, Spanier AM (1994) Unraveling the secret of meat flavor. Trends Food Sci Technol 5(10):315–321
106. Ion AC, Ion I, Culetu A, Gherase D (2010) Carbon-based nanomaterials. Environ Appl Univ Politehn Bucharest 38:129–132
107. Jadoun S, Verma A, Arif R (2020) Modification of textiles via nanomaterials and their applications. In: Frontiers of textile materials: polymers, nanomaterials, enzymes, and advanced modification techniques, pp 135–152
108. Jatoi AS, Khan FS, Mazari SA, Mubarak NM, Abro R, Ahmed J, Ahmed M, Baloch H, Sabzoi N (2021) Current applications of smart nanotextiles and future trends. Nanosensors Nanodevices Smart Multifunct Text 2021:343–365
109. Johnston BF, Mellor JW (1961) The role of agriculture in economic development. Am Econ Rev 51(4):566–593
110. Kah M, Hofmann T (2014) Nanopesticide research: current trends and future priorities. Environ Int 63:224–235
111. Karlessi T, Santamouris M, Synnefa A, Assimakopoulos D, Didaskalopoulos P, Apostolakis K (2011) Development and testing of PCM doped cool colored coatings to mitigate urban heat island and cool buildings. Build Environ 46(3):570–576
112. Karn BP, Bergeson LL (2009) Green nanotechnology: straddling promise and uncertainty. Nat Res Env't 24:9
113. Karst D, Yang Y (2006) Potential advantages and risks of nanotechnology for textiles. AATCC Rev 6(3):44–48
114. Kaul S, Gulati N, Verma D, Mukherjee S, Nagaich U (2018) Role of nanotechnology in cosmeceuticals: a review of recent advances. J Pharm
115. Kaur J, Punia S, Kumar K (2017) Need for the advanced technologies for wastewater treatment. In: Advances in environmental biotechnology. Springer, Singapore, pp 39–52
116. Kausar A (2018) Polymer coating technology for high performance applications: fundamentals and advances. J Macromol Sci Part A 55(5):440–448
117. Keat CL, Aziz A, Eid AM, Elmarzugi NA (2015) Biosynthesis of nanoparticles and silver nanoparticles. Biores Bioproc 2(1):1–1

118. Khan SH, Pathak B, Fulekar MH (2018) Synthesis, characterization and photocatalytic degradation of chlorpyrifos by novel Fe: ZnO nanocomposite material. Nanotechnol Environ Eng 3(1):1–4
119. Khan SH (2020) Green nanotechnology for the environment and sustainable development. In: Green materials for wastewater treatment. Springer, Cham, pp 13–46
120. Khin MM, Nair AS, Babu VJ, Murugan R, Ramakrishna S (2012) A review on nanomaterials for environmental remediation. Energy Environ Sci 5(8):8075–8109
121. Khot LR, Sankaran S, Maja JM, Ehsani R, Schuster EW (2012) Applications of nanomaterials in agricultural production and crop protection: a review. Crop Prot 35:64–70
122. Krishnan N, Boyd S, Somani A, Raoux S, Clark D, Dornfeld D (2008) A hybrid life cycle inventory of nano-scale semiconductor manufacturing. Environ Sci Technol 42(8):3069–3075
123. Kumar A, Kumar A, Sharma G, Naushad M, Stadler FJ, Ghfar AA, Dhiman P, Saini RV (2017) Sustainable nano-hybrids of magnetic biochar supported g-C3N4/FeVO4 for solar powered degradation of noxious pollutants-Synergism of adsorption, photocatalysis and photo-ozonation. J Clean Prod 165:431–451
124. Lam PL, Wong WY, Bian Z, Chui CH, Gambari R (2017) Recent advances in green nanoparticulate systems for drug delivery: efficient delivery and safety concern. Nanomedicine 12(4):357–385
125. Lange D, Hagleitner C, Hierlemann A, Brand O, Baltes H (2002) Complementary metal oxide semiconductor cantilever arrays on a single chip: mass-sensitive detection of volatile organic compounds. Anal Chem 74(13):3084–3095
126. Langer R (2001) Drugs on target. Science 293(5527):58–59
127. Lee RW, Shenoy DB, Sheel R (2010) Micellar nanoparticles: applications for topical and passive transdermal drug delivery. In: Handbook of non-invasive drug delivery systems. William Andrew Publishing, pp 37–58
128. Lejars M, Margaillan A, Bressy C (2012) Fouling release coatings: a nontoxic alternative to biocidal antifouling coatings. Chem Rev 112(8):4347–4390
129. Leydecker S (2008) Nano materials in architecture, interior architecture and design. In: Birkhauser, vol 43. Boston, US, 2008
130. Li Q, Hu Y, Zhang B (2021) Hydrophilic ZnO nanoparticle-based antimicrobial coatings for sandstone heritage conservation. ACS Appl Nano Mater 4(12):13908–13918
131. Ligler FS, Taitt CR, Shriver-Lake LC, Sapsford KE, Shubin Y, Golden JP (2003) Array biosensor for detection of toxins. Anal Bioanal Chem 377(3):469–477
132. Lim B, Jiang M, Camargo PH, Cho EC, Tao J, Lu X, Zhu Y, Xia Y (2009) Pd-Pt bimetallic nanodendrites with high activity for oxygen reduction. Science 324(5932):1302–1305
133. Liu R, Lal R (2015) Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. Sci Total Environ 514:131–139
134. Liu H, Webster TJ (2007) Nanomedicine for implants: a review of studies and necessary experimental tools. Biomaterials 28(2):354–369
135. Lawrence MJ, Rees GD (2000) Microemulsion-based media as novel drug delivery systems. Adv Drug Deliv Rev 45(1):89–121
136. Lohani A, Verma A, Joshi H, Yadav N, Karki N (2014) Nanotechnology-based cosmeceuticals. Int Sch Res Not
137. Lu PJ, Huang SC, Chen YP, Chiueh LC, Shih DY (2015) Analysis of titanium dioxide and zinc oxide nanoparticles in cosmetics. J Food Drug Anal 23(3):587–594
138. Lu T, Yan W, Feng G, Luo X, Hu Y, Guo J, Yu Z, Zhao Z, Ding S (2022) Singlet oxygen-promoted one-pot synthesis of highly ordered mesoporous silica materials via the radical route. Green Chem 24(12):4778–4782
139. Lund A, van der Velden NM, Persson NK, Hamedi MM, Müller C (2018) Electrically conducting fibres for e-textiles: an open playground for conjugated polymers and carbon nanomaterials. Mater Sci Eng R Rep 126:1–29
140. Maksimovic M, Omanovic-Miklicanin E (2017) Towards green nanotechnology: maximizing benefits and minimizing harm. CMBEBIH 2017. Springer, Singapore, pp 164–170

141. Martin CR (1994) Nanomaterials: a membrane-based synthetic approach. Science 266(5193):1961–1966
142. Matos J, García A, Poon PS (2010) Environmental green chemistry applications of nanoporous carbons. J Mater Sci 45(18):4934–4944
143. McNamara K, Tofail SA (2017) Nanoparticles in biomedical applications. Adv Phys: X 2(1):54–88
144. Mejía ML, Zapata J, Cuesta DP, Ortiz IC, Botero LE, Galeano BJ, Escobar NJ, Hoyos LM (2017) Properties of antibacterial nano textile for use in hospital environments. Revista Ingeniería Biomédica 11(22):13–19
145. Mishra VK, Kumar A (2009) Impact of metal nanoparticles on the plant growth promoting rhizobacteria. Dig J Nanomater Biostruct 4(3):587–592
146. Morganti P, Coltelli MB (2019) A new carrier for advanced cosmeceuticals. Cosmetics 6(1):10
147. Mu L, Sprando RL (2010) Application of nanotechnology in cosmetics. Pharm Res 27(8):1746–1749
148. Mukherjee S, Sushma V, Patra S, Barui AK, Bhadra MP, Sreedhar B, Patra CR (2012) Green chemistry approach for the synthesis and stabilization of biocompatible gold nanoparticles and their potential applications in cancer therapy. Nanotechnology 23(45):455103
149. Mukhopadhyay SS (2014) Nanotechnology in agriculture: prospects and constraints. Nanotechnol Sci Appl 7:63–71
150. Musee N (2011) Nanotechnology risk assessment from a waste management perspective: are the current tools adequate? Hum Exp Toxicol 30(8):820–835
151. Nakajima T, Shinoda K, Tsuchiya T (2014) UV-assisted nucleation and growth of oxide films from chemical solutions. Chem Soc Rev 43(7):2027–2041
152. Nasongkla N, Bey E, Ren J, Ai H, Khemtong C, Guthi JS, Chin SF, Sherry AD, Boothman DA, Gao J (2006) Multifunctional polymeric micelles as cancer-targeted, MRI-ultrasensitive drug delivery systems. Nano Lett 6(11):2427–2430
153. Nasrollahzadeh M, Sajjadi M, Sajadi SM, Issaabadi Z (2019) Green nanotechnology. In: Interface science and technology, vol 28. Elsevier, pp 145–198
154. Naushad M, Alothman ZA, Alam MM, Awual R, Eldesoky GE, Islam M (2015) Synthesis of sodium dodecyl sulfate-supported nanocomposite cation exchanger: removal and recovery of Cu2+ from synthetic, pharmaceutical and alloy samples. J Iranian Chemical Society. 12(9):1677–1686
155. Neethirajan S, Jayas DS (2011) Nanotechnology for the food and bioprocessing industries. Food Bioprocess Technol 4(1):39–47
156. Nel A, Xia T, Madler L, Li N (2006) Toxic potential of materials at the nanolevel. Science 311(5761):622–627
157. Nickols-Richardson SM, Piehowski KE (2008) Nanotechnology in nutritional sciences. Minerva Biotecnologica 20(3):117–126
158. Niidome Y, Haine AT, Niidome T (2016) Anisotropic gold-based nanoparticles: preparation, properties, and applications. Chem Lett 45(5):488–498
159. Nundy S, Ghosh A, Mallick TK (2020) Hydrophilic and superhydrophilic self-cleaning coatings by morphologically varying ZnO microstructures for photovoltaic and glazing applications. ACS Omega 5(2):1033–1039
160. Nuruzzaman MD, Rahman MM, Liu Y, Naidu R (2016) Nanoencapsulation, nano-guard for pesticides: a new window for safe application. J Agric Food Chem 64(7):1447–1483
161. OECD (2011) Fostering nanotechnology to address global challenges: water. Organisation for Economic Cooperation and Development, Paris
162. Perera S, Bhushan B, Bandara R, Rajapakse G, Rajapakse S, Bandara C (2013) Morphological, antimicrobial, durability, and physical properties of untreated and treated textiles using silver-nanoparticles. Colloids Surf, A 436:975–989
163. Prasad R, Pandey R, Barman I (2016) Engineering tailored nanoparticles with microbes: Quo Vadis? Wiley Interdiscip Rev Nanomed Nanobiotechnol 8(2):316–330
164. Prasad R (2014) Synthesis of silver nanoparticles in photosynthetic plants. J Nanoparticles 2014:1–8

165. Prasad R, Kumar V, Prasad KS (2014) Nanotechnology in sustainable agriculture: present concerns and future aspects. Afr J Biotech 13(6):705–713
166. Prasad R, Bhattacharyya A, Nguyen QD (2017) Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives. Front Microbiol 8:1014
167. Priyadarsini S, Mohanty S, Mukherjee S, Basu S, Mishra M (2018) Graphene and graphene oxide as nanomaterials for medicine and biology application. J Nanostruct Chem 8(2):123–137
168. Ramsurn H, Gupta RB (2013) Nanotechnology in solar and biofuels. ACS Sustain Chem Eng 1(7):779–797
169. Raut HK, Ganesh VA, Nair AS, Ramakrishna S (2011) Anti-reflective coatings: a critical, in-depth review. Energy Environ Sci 4(10):3779–3804
170. Raveendran P, Fu J, Wallen S (2003) Role of biopolymers in green nanotechnology. J Am Chem Soc 125:13940–13941
171. Ravichandran R (2010) Nanotechnology applications in food and food processing: innovative green approaches, opportunities and uncertainties for global market. Int J Green Nanotechnol: Phys Chem 1(2):P72–P96
172. Riaz S, Ashraf M, Hussain T, Hussain MT, Rehman A, Javid A, Iqbal K, Basit A, Aziz H (2018) Functional finishing and coloration of textiles with nanomaterials. Color Technol 134(5):327–346
173. Riaz S, Ashraf M, Hussain T, Hussain MT, Younus A (2019) Fabrication of robust multifaceted textiles by application of functionalized TiO2 nanoparticles. Colloids Surf, A 581:123799
174. Ringe K, Walz CM, Sabel BA (2004) Nanoparticle drug delivery to the brain. Encyclopedia Nanosci Nanotechnol 7:91–104
175. Robinson SM, Colborne L (1997) Enhancing roe of the green sea urchin using an artificial food source. Bull Aquac Assoc Can 1997(1):14–20
176. Roco MC (1999) Nanoparticles and nanotechnology research. J Nanopart Res 1(1):1
177. Roco MC (2003) Nanotechnology: convergence with modern biology and medicine. Curr Opin Biotechnol 14(3):337–346
178. Rosset V, Ahmed N, Zaanoun I, Stella B, Fessi H, Elaissari A (2012) Elaboration of argan oil nanocapsules containing naproxen for cosmetic and transdermal local application. J Colloid Sci Biotechnol 1(2):218–224
179. Rusinko C (2007) Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes. IEEE Trans Eng Manage 54(3):445–454
180. Sadeghzadeh B (2013) A review of zinc nutrition and plant breeding. J Soil Sci Plant Nutr 13(4):905–927
181. Saha R (2012) Cosmeceuticals and herbal drugs: practical uses. Int J Pharm Sci Res 3(1):59
182. Saha I, Bhattacharya S, Mukhopadhyay A, Chattopadhyay D, Ghosh U, Chatterjee D (2013) Role of nanotechnology in water treatment and purification: potential applications and implications. Int J Chem Sci Technol 3(3):59–64
183. Saji VS, Choe HC, Yeung KWK (2010) Nanotechnology in biomedical applications-a review. Int J Nano Biomater 3:119–139
184. Saleem H, Zaidi SJ (2020) Sustainable use of nanomaterials in textiles and their environmental impact. Materials 13(22):5134
185. Santos AC, Morais F, Simões A, Pereira I, Sequeira JA, Pereira-Silva M, Veiga F, Ribeiro A (2019) Nanotechnology for the development of new cosmetic formulations. Expert Opin Drug Deliv 16(4):313–330
186. Sawle BD, Salimath B, Deshpande R, Bedre MD, Prabhakar BK, Venkataraman A (2008) Biosynthesis and stabilization of Au and Au-Ag alloy nanoparticles by fungus, Fusarium semitectum. Sci Technol Adv Mater 9(3):035012
187. Schoden F (2021) Ecological and sustainable smart nanotextile. In: Nanosensors and nanodevices for smart multifunctional textiles. Elsevier, pp 287–320
188. Seil JT, Webster TJ (2012) Antimicrobial applications of nanotechnology: methods and literature. Int J Nanomed 7:2767

189. Sekhon BS (2014) Nanotechnology in agri-food production: an overview. Nanotechnol Sci Appl 7:31
190. Sertova NM (2015) Application of nanotechnology in detection of mycotoxins and in agricultural sector. J Cent Euro Agric 16:117–130
191. Shabbir M, Kaushik M (2020) Engineered nanomaterials: scope in today's textile industry. In: Handbook of nanomaterials for manufacturing applications. Elsevier, pp 249–263
192. Shahverdi AR, Fakhimi A, Shahverdi HR, Minaian S (2007) Synthesis and effect of silver nanoparticles on the antibacterial activity of different antibiotics against Staphylococcus aureus and Escherichia coli. Nanomed: Nanotechnol, Biol Med 3(2):168–171
193. Shapira P, Youtie J (2015) The economic contributions of nanotechnology to green and sustainable growth. In: Green processes for nanotechnology. Springer, Cham, pp 409–434
194. Shi J, Votruba AR, Farokhzad OC, Langer R (2010) Nanotechnology in drug delivery and tissue engineering: from discovery to applications. Nano Lett 10(9):3223–3230
195. Siddiqi KS, Husen A, Rao RA (2018) A review on biosynthesis of silver nanoparticles and their biocidal properties. J. Nanobiotechnol. 16(1):1–28
196. Silva IO, Ladchumananandasivam R, Nascimento JH, Silva KK, Oliveira FR, Souto AP, Felgueiras HP, Zille A (2019) Multifunctional chitosan/gold nanoparticles coatings for biomedical textiles. Nanomaterials 9(8):1064
197. Singh R, Tiwari S, Tawaniya J (2013) Review on nanotechnology with several aspects. Int J Res Comput Eng Electron 2(3):1–8
198. Singh R, Shedbalkar UU, Wadhwani SA, Chopade BA (2015) Bacteriagenic silver nanoparticles: synthesis, mechanism, and applications. Appl Microbiol Biotechnol 99(11):4579–4593
199. Singh P, Pandit S, Mokkapati VR, Garg A, Ravikumar V, Mijakovic I (2018) Gold nanoparticles in diagnostics and therapeutics for human cancer. Int J Mol Sci 19(7):1979
200. Singh M, Vajpayee M, Ledwani L (2020) Eco-friendly surface modification and nanofinishing of textile polymers to enhance functionalization. Nanotechnol Energy Environ Eng 2020:529–559
201. Smith GB, Gentle A, Swift P, Earp A, Mronga N (2003) Coloured paints based on coated flakes of metal as the pigment, for enhanced solar reflectance and cooler interiors: description and theory. Sol Energy Mater Sol Cells 79(2):163–177
202. Smith GB (2011) Green nanotechnology. In: Nanostructured thin films IV, vol 8104. SPIE, pp 9–22
203. Smol JP, Stoermer EF (2010) The diatoms: applications for the environmental and earth sciences. Cambridge University Press, Cambridge
204. Som C, Berges M, Chaudhry Q, Dusinska M, Fernandes TF, Olsen SI, Nowack B (2010) The importance of life cycle concepts for the development of safe nanoproducts. Toxicology 269(2–3):160–169
205. Some S, Sen IK, Mandal A, Aslan T, Ustun Y, Yilmaz EŞ, Katı A, Demirbas A, Mandal AK, Ocsoy I (2018) Biosynthesis of silver nanoparticles and their versatile antimicrobial properties. Mater Res Exp 6(1):012001
206. Soni V, Chandel S, Jain P, Asati S (2016) Role of liposomal drug-delivery system in cosmetics. In: Nanobiomaterials in Galenic formulations and cosmetics. William Andrew Publishing, pp 93–120
207. Sonneville-Aubrun O, Simonnet JT, L'alloret F (2004) Nanoemulsions: a new vehicle for skincare products. Adv Colloid Interface Sci 108:145–149
208. Souto EB, Müller RH (2008) Cosmetic features and applications of lipid nanoparticles (SLN®, NLC®). Int J Cosmet Sci 30(3):157–165
209. Souto T, Almeida M, Leal V, Machado J, Mendes A (2020) Total solar reflectance optimization of the external paint coat in residential buildings located in mediterranean climates. Energies 13(11):2729
210. Sozer N, Kokini JL (2009) Nanotechnology and its applications in the food sector. Trends Biotechnol 27(2):82–89
211. The Eleventh ASEAN Food Conference; 21–23 October 2009; Bandar Seri Begawan, Brunei Darussalam

212. Tennakone K, Kumara GR, Kumarasinghe AR, Wijayantha KG, Sirimanne PM (1995) A dye-sensitized nano-porous solid-state photovoltaic cell. Semicond Sci Technol 10(12):1689
213. Thornhill S, Vargyas E, Fitzgerald T, Chisholm N (2016) Household food security and biofuel feedstock production in rural Mozambique and Tanzania. Food Secur 8(5):953–971
214. Tiwari DK, Behari J, Sen P (2008) Application of nanoparticles in waste water treatment. World Appl Sci J 3:417–433
215. Tratnyek PG, Johnson RL (2006) Nanotechnologies for environmental cleanup. Nano Today 1(2):44–48
216. Ulijn RV, Bibi N, Jayawarna V, Thornton PD, Todd SJ, Mart RJ, Smith AM, Gough JE (2007) Bioresponsive hydrogels. Mater Today 10(4):40–48
217. U. S. Food, and Drug Administration (2018) Is it a cosmetic, a drug, or both? (Or is it soap?). Available online at: https://www.fda.gov/cosmetics/guidanceregulation/lawsregulations/ucm074201.htm. Accessed 02 Aug 2018
218. Ul-Islam S, Butola BS (2018) Nanomaterials in the wet processing of textiles. John Wiley & Sons
219. van Amerongen A, Barug D, Lauwaars M (2007) Rapid methods for food and feed quality determination. Wageningen Academic Publishers
220. Verma A, Gautam SP, Bansal KK, Prabhakar N, Rosenholm JM (2019) Green nanotechnology: advancement in phytoformulation research. Medicines 6(1):39
221. Viswanathan S, Radecki J (2008) Nanomaterials in electrochemical biosensors for food analysis-a review. Polish J Food Nutr Sci 58(2):157–164
222. Wang X, Zhi L, Müllen K (2008) Transparent, conductive graphene electrodes for dye-sensitized solar cells. Nano Lett 8(1):323–327
223. Watanabe J, Iwamoto S, Ichikawa S (2005) Entrapment of some compounds into biocompatible nano-sized particles and their releasing properties. Colloids Surf, B 42(2):141–146
224. West JL, Halas NJ (2000) Applications of nanotechnology to biotechnology: commentary. Curr Opin Biotechnol 11(2):215–217
225. Winkler G (2011) Green facilities: industrial and commercial LEED certification. GreenSource, 1st edn. The McGraw-Hill Companies, Inc
226. Wu Q, Zhang Q, Zhao L, Li SN, Wu LB, Jiang JX, Tang LC (2017) A novel and facile strategy for highly flame retardant polymer foam composite materials: transforming silicone resin coating into silica self-extinguishing layer. J Hazard Mater 336:222–231
227. Wu Y, Zhao Y, Han X, Jiang G, Shi J, Liu P, Khan MZ, Huhtinen H, Zhu J, Jin Z, Yamada Y (2021) Ultra-fast growth of cuprate superconducting films: dual-phase liquid assisted epitaxy and strong flux pinning. Mater Today Phys 18:100400
228. Xiang T, Lv Z, Wei F, Liu J, Dong W, Li C, Zhao Y, Chen D (2019) Superhydrophobic civil engineering materials: a review from recent developments. Coatings 9(11):753
229. Xu H, Li Y, Huang NJ, Yu ZR, Wang PH, Zhang ZH, Xia QQ, Gong LX, Li SN, Zhao L, Zhang GD (2019) Temperature-triggered sensitive resistance transition of graphene oxide wide-ribbons wrapped sponge for fire ultrafast detecting and early warning. J Hazard Mater 363:286–294
230. Xue CH, Wu Y, Guo XJ, Liu BY, Wang HD, Jia ST (2020) Superhydrophobic, flame-retardant and conductive cotton fabrics via layer-by-layer assembly of carbon nanotubes for flexible sensing electronics. Cellulose 27(6):3455–3468
231. Yeh MI, Huang HC, Liaw JH, Huang MC, Huang KF, Hsu FL (2013) Dermal delivery by niosomes of black tea extract as a sunscreen agent. Int J Dermatol 52(2):239–245
232. Yih TC, Al-Fandi M (2006) Engineered nanoparticles as precise drug delivery systems. J Cellular Biochem 97(6):1184–1190
233. Yilmaz ND (2018) Introduction to smart nanotextiles. Smart Text Wearable Nanotechnol 16:1–37
234. Yu ZR, Mao M, Li SN, Xia QQ, Cao CF, Zhao L, Zhang GD, Zheng ZJ, Gao JF, Tang LC (2021) Facile and green synthesis of mechanically flexible and flame-retardant clay/graphene oxide nanoribbon interconnected networks for fire safety and prevention. Chem Eng J 405:126620

235. Yukuyama MN, Ghisleni DD, Pinto TD, Bou-Chacra NA (2016) Nanoemulsion: process selection and application in cosmetics–a review. Int J Cosmet Sci 38(1):13–24
236. Yunlong C, Smit B (1994) Sustainability in agriculture: a general review. Agr Ecosyst Environ 49(3):299–307
237. Zhang WX (2003) Nanoscale iron particles for environmental remediation: an overview. J Nanopart Res 5(3):323–332
238. Zhang H, Lamb R, Lewis J (2005) Engineering nanoscale roughness on hydrophobic surface-preliminary assessment of fouling behaviour. Sci Technol Adv Mater 6(3–4):236–239
239. Zhang Q, Han L, Jing H, Blom DA, Lin Y, Xin HL, Wang H (2016) Facet control of gold nanorods. ACS Nano 10(2):2960–2974
240. Zheng L, Xiong T, Shah KW (2019) Transparent nanomaterial-based solar cool coatings: synthesis, morphologies and applications. Sol Energy 193:837–858
241. Zhu Q, Chua MH, Ong PJ, Lee JJ, Chin KL, Wang S, Kai D, Ji R, Kong J, Dong Z, Xu J (2022) Recent advances in nanotechnology-based functional coatings for the built environment. Mater Today Adv 15:100270
242. Zou H, Wu S, Shen J (2008) Polymer/silica nanocomposites: preparation, characterization, properties, and applications. Chem Rev 108(9):3893–3957
243. Zou GF, Zhao J, Luo HM, McCleskey TM, Burrell AK, Jia QX (2013) Polymer-assisted-deposition: a chemical solution route for a wide range of materials. Chem Soc Rev 42(2):439–449