Nanotechnology for Environmental Engineering (2023) 8:1–14
https://doi.org/10.1007/s41204-022-00293-7

CRITICAL REVIEWS

Future adoption and consumption of green and sustainable nanoproducts—classifications and synthesis

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Received: 23 October 2021 / Accepted: 25 September 2022 / Published online: 10 November 2022

Abstract

Nanotechnology has paved the path into our daily lives in the form of consumer products, ranging from food products to the textile we wear. With this huge inflow of nanoproducts, research has been able to draw conclusions that these products are environment friendly and sustainable for our planet. This particular chapter will bring out the intrinsic arenas, where the usage of nanotechnology and its products has led to a green future and eco-friendly living. There are numerous nanoproducts which are a remedy to the existing scenario of pollution and miseries of human. To add to it, nanotechnology has been of importance to revamp clean energy movement and bring about various techniques to limit the pollution. The basis of green nanoproducts is to make earth less hazardous and less toxic planet to live in. We have put up various intriguing case studies and contemporary research on nanotechnology that is of great importance in the view of sustainability and green future. The upcoming times are waiting for better improvised techniques to deal with existing dreadful pollution and the deadly climate change. Nanotechnology and the products built through nanoscience will play a crucial role in mitigating the issues of our blue planet.

Keywords Nanomaterial · Nanoproduct · Sustainable future

Introduction

Nanoproducts are the products derived from the intensive use of nanotechnology in order to gain specific physical, chemical, and structural properties. Consumer nanoproducts have been of significant importance in the economy of the nation; the ultimate motive has been to reduce the impact of nanoproducts on the environment by making the process green and sustainable. Earlier studies and reports have proved that nanotechnology is potentially the next great commercial opportunity offering investors a good deal to bag some commercial potential. The global market for nanoproducts is estimated to reach 125 billion USD in 2024, as nearly all daily usage products can be enhanced by using nanoparticles in them. Commercialization for nanoproducts ensures that it will not only meet the performance and reliability requirements but will also fulfil economic needs [50, 80, 81]. The use of nanoproducts implementing engineered nanoparticles can be proved cost-effective, green, and sustainable alternative to using traditional materials. The engineered nanoparticles used in manufacturing various nanoproducts and their life cycle can be obtained by applying that particle within that particular product. Relevant exposure, ageing, and transformation are firmly subject to the life cycle of nanoproducts [58]. The primary property of nanoparticles which is a larger surface area to mass ratio is what makes them advantageous.

Nanotechnology will open up the horizon of new products, keeping in mind environmental concerns. It may include making solar cells better in terms of efficiency of electricity generation and cleaning polluted water. It is the process of creating and utilizing materials, devices, and systems by manipulating matter on a nanometer scale. Consumer nanoproducts have been commercialized and their usage has greatly increased in number over the last two decades. The increase in the use of nanoproducts for cosmetics, paints, polymers, food packaging, medical, electronics, aeronautics, sports, and textiles has shown an equal rise and thousands of nanoproducts are available commercially. Along with the development of nanoproducts, development

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of databases and inventories containing information related to engineered nanomaterials used for manufacturing [64]. Various inventories, like nanotechnologies project, and nanoproducts data bank are there which provides the information about the nanomaterials and nanoproducts which are currently in existence in European Association for the co-ordination of consumer representation in standardization [62]. Other aspect for the development in this field is the sustainable manufacturing of the nanomaterials.

Sustainable development through nanoproducts still has some hurdles to overcome like lowering the price of nanomaterials, incorporating nano-based technology in the industry, making it acceptable socially and studying the risk of nanomaterials to our environment. With an increase in the use of engineered nanomaterials, their trivial, inadvertent and deliberate release in the environment has increased, and nano-aggregates of silver and titanium dioxide have already been found in the environment. Wastewater treatment and waste management are not equipped with technologies able to remove the engineered nanoparticles [72]. Another important area is construction; one of the most widely utilised construction materials is concrete. There is a need for rapid development in understanding the cementitious material at the micro-level. The strength and durability of the concrete can be enhanced if the porosity is reduced by nano-additives. Substances like nanotubes or fibres, nano-clay and nanoscale spherical materials are used to improvise the strength and durability of the concrete. The construction industry will be one of the most important industries using nanoparticles but most of the materials are at a laboratory scale [63]. Nanomaterials have their applications in almost every field; we will take some of the important fields and see the usage of nanomaterials in that field.

Food packaging is an important field where nanoproducts can be used. Materials like biopolymers, paper, glass and metals have been used as packing products till now. Currently, a wide range of engineered nanoparticles has been introduced for food packaging. Materials like silver NPs (AgNPs), nano-clay, nano-zinc oxide, nano-scaled cellulose, nano-starch, carbon nanotubes and nano-silica are used in food packaging as they have properties like flexibility, durability, flame resistance, barrier properties and recycling properties [15]. Nano-packaging also serves as a foodborne disease barrier; they are smart toxin-detector that alarms with the signs of non-uniform quality [73].

Agriculture acts as an important pillar in developing the country's economy. Nanoproducts-based sustainable development is also possible in the agricultural sector and food science, as it is an urgent requirement to satisfy the global nutrition demand as by conventional farming almost one-third of the crop gets damaged due to natural phenomena or by pesticides, poor soil quality and microbial attacks. Nano-based products are becoming new age materials to transform modern agriculture practices. Nanomaterials can be employed as a smart coating for agricultural feed such as pesticides and efficient soil management can also be implemented [57, 85]. Nanoproducts in the food manufacturing sector could help market mediators and also lower the production costs by generating non-fouling surfaces that prevent congestion in process machinery [77]. With supplemented nutrients of various flavours, certain nanoproducts could increase bioavailability [30, 46]. As the population of the world is increasing there is a need to produce almost 50% more to match the requirements, nanotechnology plays a vital role in satisfying the needs [89]. Nanosilver can also be used as a nanoproduct in medical applications, as the size of nanosilver is smaller than 100 nm and contain 20–15,000 Ag-atoms. It has strong antimicrobial properties; it is promoted as a water disinfectant and room spray, used for treating wounds and burns or as a contraceptive. Thus, the use of nanosilver as medical-related work is increasing more and more. Nanosilver is also used as a detergent, incorporated in textiles, water purification and wall paints. Furthermore, nanosilvers are generally non-toxic products; it only affects people with chronic disease [16].

There are certain disadvantages of using nanoproducts such as it is unstable in hostile conditions, toxicity to the environment, and the challenge of recycling them. So for eco-friendly manufacturing and sustainable products, green nanoproducts are manufactured. Green nanoproducts are the products that cause the least harm to the environment and their synthesis is done using various bioactive agents which include plants, fruit peel waste, and various other bio-wastes. Sustainable nanoproducts mean nanoproduct which uses renewable materials for manufacturing and has a low influence on the environment. Nanoproducts used for the adsorbent in water treatment are observed to be manufactured using plant extract or some bio-wastes which are termed green nanomaterials as it does not have any harmful effect on the environment. The main of green nanoproducts is to reduce the harmful by-products which are produced while using conventional nanoproducts. Researchers should focus on synthesizing nanoproducts that are based on bioactive agents and are sustainable; doing this, the limitations of conventional nanoproducts can be overcome and can aid in creating a sustainable and eco-friendly future.

As clean water is utmost essential for human life, its quality should be maintained and it should not be contaminated. It is observed that green synthesised nanoparticles are largely used in the treatment of waste water containing inorganic pollutants. Waste water treatment works on the principle of adsorption, and it is well known that nanoparticles have a higher surface area which is one of the important aspects of adsorption process. Due to its higher specific surface area, unique adsorption phenomenon and wide distribution of reactive surface sites nanoparticles adsorbent have better adsorption capacity compared to other adsorbents [22]. Many such works have been done in finding effective adsorbents for the removal of contamination such as arsenic, fluoride, and nitrates [85] in their research work formulated the use of green synthesized iron nanoparticles for the removal of nitrate contamination using green tea and eucalyptus leaves extract as adsorbent. It was found that it was more effective rather than using other materials. Many such studies are carried out like [93] used hydrous titanium dioxide ($TiO2 \cdot xH2O$) nanoparticles, (S. H. [94] formulated usage of **Ti-loaded basic yttrium carbonate (Ti-BYC)** for the removal of arsenic contamination. Along with that for fluoride contamination [91] incorporated the use of Lanthanum–iron binary oxide nanoparticles, [92] used Perovskite lanthanum aluminate nanoparticles. Along with all these research works, many other studies have suggested nanoparticles are effective when used as adsorbents for the removal of water contamination. If these nanoparticle adsorbents are synthesized in an eco-friendly manner, they are termed green nanoparticles. More such uses of the green nanoparticles are incorporated in this paper in different sections ahead.

Along with all the applications of nanoproducts, the end of line is the point at which the product no longer meets the user's needs. These products cause harm to the environment, so it is necessary to manage these products and recycle them [7]. Nanocomposites in the automobile industry were investigated, and it was found that recyclability and reparability are important for these industries. The consumer end products used such as cosmetics, textiles, packaging, and agricultural products are aimed to be produced in a sustainable and eco-friendly manner.

Classification of nanoproducts

Nanoproducts are mainly classified into four different categories they are as follows. Figure 1 represents a brief classification of nanoproducts.

Carbon-based nanoproducts

Carbon-based nanoproducts have become important products because of their unique combinations in properties such as chemical and physical along with it properties like mechanical, electrical, thermal and optical properties. Extensive research works are going on for using these products for human benefits [14]. Carbon-based nanoproducts are mostly used in therapeutics, biomedical imaging, biosensors tissue engineering and various other categories. There are various nanoproducts which are based on carbon.

1. Carbon nanotubes (CNTs)

Carbon nanotubes are cylindrical structures consisting of one or more layers of graphene. Perfect CNTs have all the carbon atoms bonded in a hexagonal lattice except their end. While bulk production of CNTs can have a mixture of pentagon, hexagon or other random structures which will degrade its quality [55]. The thickness of carbon nanotubes is 50,000 times smaller than the width of human hair. CNTs are divided into two categories single-walled nanotubes and multi-walled nanotubes. It belongs to the fullerene family which also includes buckyball [65].

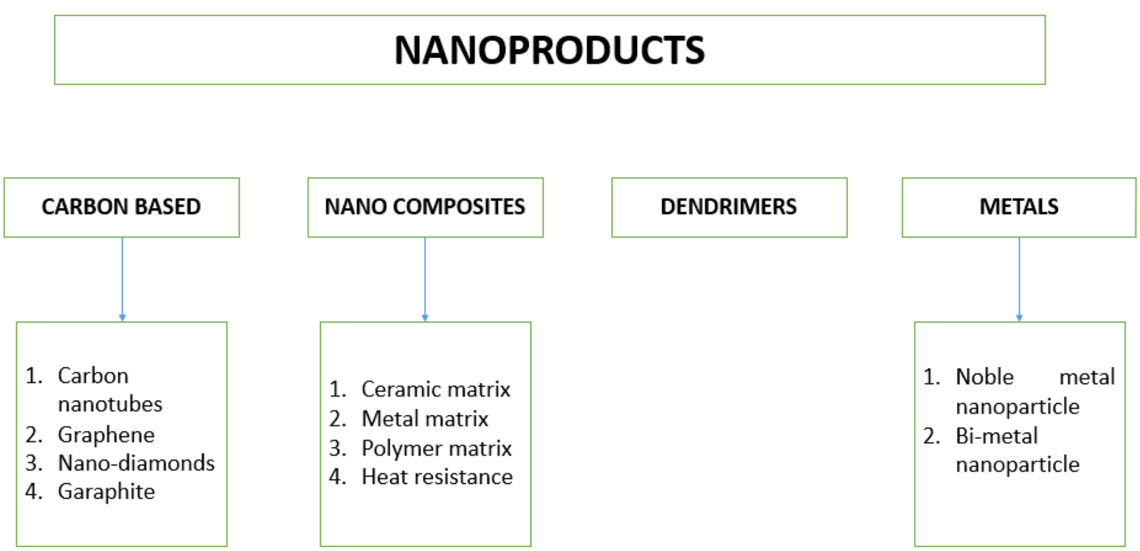

Fig. 1 Represents the classification of nanoproducts

CNTs can be used for the anode; it may enable the use of low grade heat through an osmotic heat engine [55]. It is also used in drug delivery systems, atomic force microscope, electrochemical reactions as microelectrodes, and it is good media for the storage of lithium and hydrogen. It is also used in vacuum microelectronics, energy storage and hydrogen storage, used in the formation of ultimate carbon fibres [5]. Thus, these are the potential uses of carbon nanotubes.

2. Graphite

The structure of graphite contains atoms of carbon which are connected in a huge flat network and are then placed on one another. It is very flexible but it cannot be termed as an elastic material. It behaves as both metals and non-metals. Along with that, it is greyish black in nature, possesses high thermal conductivity and is chemically inert [13, 20, 76].

Graphite nanomaterials are used as piston rings, thrust bearings, journal bearings, vanes, shaft and fuel pumps of many aircraft engines. It is also used in carbon raising in olten steel and lubricant in dyes to extrude hot steel.

3. Nanodiamond

No other material possesses thermal conductivity as high as diamond but it has a poor dielectric constant and it is most likely that it shows affinity to electrons when tested. Along with it, it has great carrier mobility, electric field and saturated carrier velocities [67]. Thus, products of nanodiamonds can have a lot of benefits when used.

It is used as electrolytic and electroless metal plating, also used as chemical vapour dissolution for diamond films, magnetic image resonance chromatography, proteomics and spectrometry. Nanodiamonds doped with boron have conducting nature and can be utilized for electro-analysis, electrochemical double-layer capacitors and batteries [61].

4. Graphene

Graphene is the basic building block of all graphitic forms; it has a closely packed single layer of carbon atoms. It has a large surface area, and both sides of the sheet are available for molecule adsorption [68]. Graphene can be easily modified by a functional group like graphene oxide.

It is mainly used in adsorption processes for different sample preparation methods. It is used in the sample preparation methods of chlorophenols, lead, chromium (III) glutathione neurotransmitters, etc [90].

Nanocomposites products

Nanocomposites are the materials which are formed by nanosized particles into a matrix of standard materials. Nanocomposites consist of hydrogels [95]; this will show a drastic change in properties of that material which will include mechanical strength, toughness and electrical or thermal conductivity. Nanoparticles and hydrogel form advanced materials with different properties which were earlier absent in the individual particles. One of the earliest investigations of such materials was done by **(Yissar et al., 2001),** in which they immobilized gold in polyacrylamide (PAAm) by swelling the hydrated gel with Au-NP solution present, which resulted in the gold nanoparticles being uniformly distributed in the gel matrix. Such unique approaches are reported by researchers and are used in biomedicine and optics. There are different types of nanocomposites. The first one is micro- or nanogels which stabilize single or multiple nanoparticles, the second is immobilized and non-covalently nanoparticles in a hydrogel matrix and the last one is covalently immobilized nanoparticles hydrogel matrix [80]. Their highly crystalline nature, high specific ratio, regular shape and low cost are the major properties of nanocomposites. Nanocomposites are classified in the following ways.

1. Ceramic matrix nanocomposites—it consists of ceramic fibres embedded in ceramic matrix.
2. Metal matrix nanocomposites—it is reinforced metal matrix composites, metal embedded in metal matrix
3. Polymer matrix nanocomposites—nanoparticles added to the polymer matrix
4. Magnetic nanocomposites—it includes matrix dispersed nanoparticles, core shell nanoparticles, colloidal crystals, macroscale spheres and Janus type nanostructure [10, 11].
5. Heat Resistannce nanocomposites- it is used ot withstand higher temperature, for example, the carbon dots in polymer matrix [69].

As we know, nanocomposites have great application in medical science; their higher surface area to volume ratio allows increased loading of therapeutics. **(G. Wang and Su, 2011).** Nanocomposites are also used as fillers for superior elasticity and dermatological patches. When materials like CNTs and graphene oxide are placed in hydrogels, they work as a light absorbing material which is useful for photothermal drug delivery [80]. Nanocomposites can also be used in handling tasks while dealing with acid and oxide, it will also avoid the environmental complications of chemical treatment [41].

Dendrimers

Dendrimers are one of the most crucial classes of nano-fraternity. They have a wide scope of use in medicine, biotechnology and the biochemical sector. Dendrimers are nanoparticles that are radially symmetrical, hyper branched and have three-dimensional polymeric structure. There is a high crowding of the functional group present on the dendrimers' surface. The dendrimer has three domains present, namely core, dendrons and terminal functional group. Dendrimeric crevices are cavities created between dendrons that can contain the guest molecule through hydrophobic or electrostatic interactions [9]. The term "Dendrimer" is used as a motif for the peculiar structure. They are synonymous to "cascade molecules" [2]. Their structure consists of a central atom that is the core, dendrons are the branches attached to the central atom and there may be numerous functional groups attached trailing to these branches. The core, the interior (or branches), and the perimeter are the three distinct regions of a dendron (or end groups) [47]. Dendrimers are either highly ambiguous or have a very restricted structural variety. The dendrimers can be manipulated in the context of their molecular weight and chemical composition, during the synthesis period. With increasing dendrimer generation, dendritic macromolecules tend to grow in diameter and take on a more globular form. Dendrimers are used for applications such as drug carrier, anticancer drugs, and stabilizers. Pharmacokinetic qualities are considered when using dendrimers in biomedical usages such as drug delivery, imaging, photodynamic therapy, and neutron capture treatment. Dendritic polymers are functionalized in the same way that proteins, enzymes, and viruses are. Dendrimers and other molecules can be enclosed in their interior voids or connected to the periphery. Metal chelates based on dendrimers are used as contrast agents in magnetic resonance imaging [65]. Other applications of dendrimers include gene delivery, enhancement of solubility, photodynamic therapy, water purification, anti-tumour therapy, catalysis, separating agents and printing inks and paints.

Metallic

Metallic nanoparticles are metals having dimensions (length, breadth, and thickness) between 1 and 100 nm. These nanomaterials can be made and controlled to attach to the antibodies, ligands, and drugs using a variety of chemical functional groups. Metal nanoparticles are important because of vast medicinal, consumer, industrial, and military applications. Hence, metal NPs have attracted a lot of attention. Although the same material is largely benign in its bulk form, several metal-based nanoparticles demonstrate enhanced toxicity as particle size decreases (e.g., Cu, Au and Ag). Some of the peculiar properties of metal nanoparticles are enhanced Rayleigh scattering, surface enhanced Raman scattering, strong plasma absorption, biological system imaging, and determining chemical information on the metallic nanoscale substrate [83]. New reactive metal nanomaterials are being developed because of their potential use in propellants, explosives, and pyrotechnics.

The aluminium nanoparticles are used as a fuel-propellant, ablation resistant coating additive and as explosives. Gold nanoparticles find their use in photochemotherapy and cellular imaging. Oxides of iron are needed in order to remediate the environment and are used in magnetic resonance imaging. Silica dioxide is used as catalyst supports, drug carriers, adsorbents and in the making of electric/thermal insulators. Silver nanoparticles are used in photography, electrical equipment, batteries and also possess antibacterial properties. Copper nanoparticles have medicinal use as they are antimicrobial in nature and are also used in lubrication and as catalysts. Cerium dioxide (in nano-form) is used in polishing, computer chip manufacturing and as a fuel additive to decrease emissions. Nanoparticles of oxides of manganese are used in batteries and for catalysis. Ni-oxides are good conductors and possess great magnetic properties. Titanium dioxide nanoparticles are needed in photocatalysis, sterilization, paints and cosmetics. Zinc oxides are used to make skincare products.

These are the specific types of nanoproducts classified according to terms of their usage, structure and properties.

Synthesis and manufacturing of nanoproducts

Carbon nanotubes (CNTs)

Carbon nanotubes are of two types, single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Mainly CNTs are formed by four different methods they are as follows.

Electric arc discharge

This method uses a higher temperature, i.e., above 1700 °C for the synthesis of CNT. This manufacturing method helps the expansion of carbon nanotube with lesser defects in its structure compared to other processes. High purity graphite electrodes and water cooled electrodes are used in this method in a chamber having helium. Cathode and anode of graphite are incorporated, along with the metal catalysts, electrodes and evaporated carbon molecules. Direct pressurized current is passed through the chamber and when the chamber gets heated, half of the carbon atoms will be solidified and deposited on the cathode. In this process, the anode is consumed and cigar type structure is formed at the cathode. Generally in this method, the preparation of SWNTs catalyst is needed, while for MWNTs there is no need for a catalyst [25].

Laser ablation method

In this method, laser-vapourization at high power along with block graphite having quartz tube is heated in a furnace at 1200 degrees Celsius in Ar atmosphere [2]. The use of laser will vapourize the graphite in the quartz tube. If the laser power is increased, the diameter will be thinner **(Yacaman et al. 1993);** it is proved that laser pulses help in creating a large amount of single-walled nanotubes [46]. This method gives a higher yield compared to any other method; plus it has lower metallic impurities. However, the only disadvantage is that this method can give some branched nanotubes. But this method is not economically viable as it requires high purity of graphite rods and the productivity is less compared to the arc discharge technique.

Chemical vapour deposition (CVD)

It is the most used method for the synthesis of carbon nanotube. Catalytic chemical vapour deposition (CCVD) [26], plasma enhanced (PE), oxygen-assisted CVD [37], water-assisted CVD [26, 35, 42], microwave plasma (MPECVD), and radio frequency (RF-CVD) [12] are the different types of CVD available. Amongst all these, CCVD is the most used technique for the manufacturing of CNT. This technique involves the hydro carbon substrate's chemical breakdown. It can reach 90–95% selectivity for single-walled nanotube at optimized conditions [17, 49]. Secondly, using high melting point alloys as catalysts provides higher yield up to 99% of SWNTs, as due to the high melting point the catalyst remains in solid state [23]. CNTs can be prepared in horizontal furnaces and fluidized beds. CVD is used for large-scale production and is used worldwide as a production technique. It is used on large scale because it provides uniform heat and mass transfer, sufficient space for the growth of the material and continuous operation [39].

Graphene nanoproducts from graphite exfoliation

Graphene and graphene-based nanoproducts are synthesized in such a way that their properties can be altered and can be used for different applications. The production of graphene can proceed in two ways; bottom-up and top-down prepared by alternative carbon sources and separation of stacked layers, respectively. There are several methods which are developed over the years to synthesise graphene [19], they are as follows.

Liquid-phase exfoliation for the synthesis of graphite is done by wet chemical dispersion and later, in an appropriate solvent sonication-induced exfoliation is done, it may or may not include surfactants. By this method, the graphite is converted to a graphene sheet [34]. Nowadays, a green method is developed for the synthesis of graphene containing few layers; it is prepared by using pure water without any surfactants or chemicals [22]. In this technique, they have used facile liquid exfoliation with vapour pre-treatment for the preparation of edge hydroxylated graphene. Water dispersed in graphene is used to get an ultrathin conductive film made of graphene nanoplatelets. This method was cost-effective and has environmental friendly synthesis of graphene-based nanoproducts with due real-life application.

Exfoliation is the process in which there is a breaking of layered materials of graphite forming a 2-dimensional sheet, flat and having atomic thickness. The first attempt at the synthesis of graphene was made by doing exfoliation of highly oriented pyrolytic graphite with scotch tape [43]. Another method is also used where natural graphite is reduced to graphene oxide by Hummer's method [47].

Synthesis of nanodiamond

Nanodiamonds can be produced from the molecules of explosives which can provide both a source of carbon and energy for the conversion. This is the most viable and environmental friendly method [61].

Among various techniques for the synthesis of nanodiamonds, detonation is a widely used technique; it has three variants. Transformation of the phase of graphite along with energy shock waves is the first variant used in manufacturing; this process happens in a closed chamber. It is a popular technique for the synthesis of polycrystalline nanodiamonds. The other variant is done by using explosives such as hexogen, octogen, trinitrotoluene or a mixture of all such explosives, along with it sometimes a mixture of TNT/RDX is also used. This explosive provides high energy for the nanocrystalline particles to be formed [51]. There are two types of processes occurring in the synthesis of nanodiamonds based on the amount of coolant used; processes are categorized as wet or dry processes [82]. The yield of the process increases based on the coolant used in the series hydrogen < argon < nitrogen < CO_2. The third variant was developed in USSR and is less known [29]. In this method, various explosives are used in different compositions for the formation of nanodiamonds [44].

Nanocomposites

Reinforcement in composites are classified into microscopic, macroscopic or nanoscopic particles, woven, continuous and short fibres and particles or morphologically, based on their physical size. By the addition of nanoparticles or nanoproducts, the properties can be improved because of higher specific surface area. Properties of materials can be enhanced by the addition of nano-reinforcement because it possess higher specific surface area [56]. Ceramic matrix composites are synthesized by various techniques. Hot pressing is conventional technique used for the synthesis of ceramic and nanocomposites. In this technique, carbon fibres are used as additives [6].

There are various methods for the preparation of ceramic nanocomposites; amongst them, solid-phase technology is the least widespread one. In this method, the powder form of matrix component is mixed with reinforced filler in the form of short fibres or whiskers; polymer binder is also added in a small amount. The mixture formed is then pressed and sintered at high temperature. In this method, the use of whiskers tends to form agglomerates and can reduce the work-piece density. Figure 2 represents the process flow for solid-phase technology [31]. Liquid-phase preparation of ceramic nanocomposites and its vapour- and gas-phase methods are also used for the synthesis of ceramic nanocomposites.

Metal matrix nanocomposites possess improved physical properties as compared to the alloy they are derived from; these properties are added by different types of addition of reinforcement of different shapes, sizes etc. There are various techniques used for the manufacture of metal matrix nanocomposites; they are as follows. One of them is the self-lubricating metal matrix composites. In this method, properties like water control, controlled heat dissipation, controlled dissipation of energy, and lubricant usage reduction are the strategies for efficient, sustainable and green products. Silicon carbide is an additive which is used with aluminium to reduce wear resistance. This can help in increasing the life of transportation equipment; aluminium graphite solid lubricant can cause a significant decrease in frictional energy loss and can also eliminate size-related concerns such as piston, cylinder liners and bearing applications. Self-heating metal matrix is the materials that either by outside or independently repair the damages such as voids and cracks on the materials they are applied [70].

Polymeric nanocomposites are synthesized by dispersion of fillers in a polymer matrix [45]. They are synthesized by to approaches top-down or bottom-up.

The overview of these methodologies is mentioned in Figs. 3 and 4

Dendrimers

Dendrimers straddle the line between molecular and polymer chemistry. They are related to molecular chemistry because of their step-by-step regulated production, and they are related to polymers because of their repeated monomer structure. Dendrimer synthesis allows for the creation of monodisperse, structure-controlled macromolecular architectures that are similar to those found in biological systems [2].

Dendrimers are typically made using either a divergent or convergent approach. Dendrimer expands outward from a multifunctional core molecule in each approach. The first-generation dendrimer is formed when the core molecule combines with monomer molecules having one reactive and

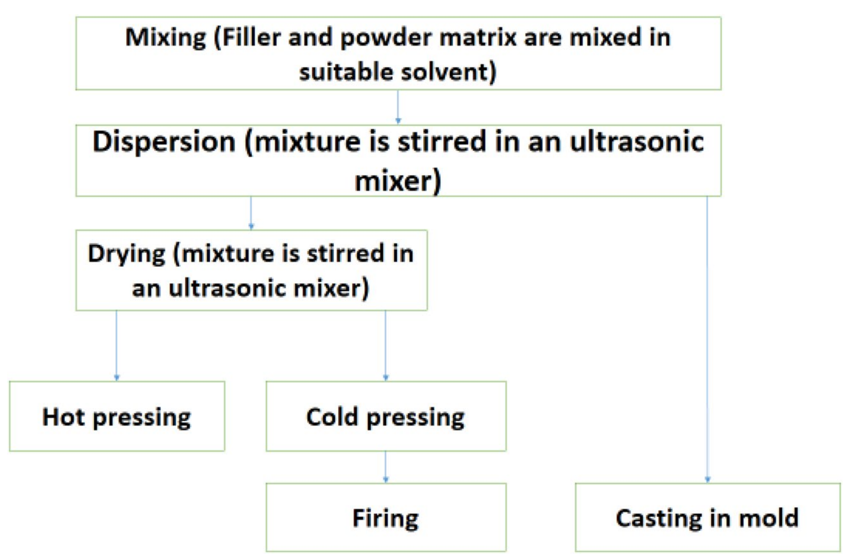

Fig. 2 Represents the process flow diagram for solid-phase technology [27]

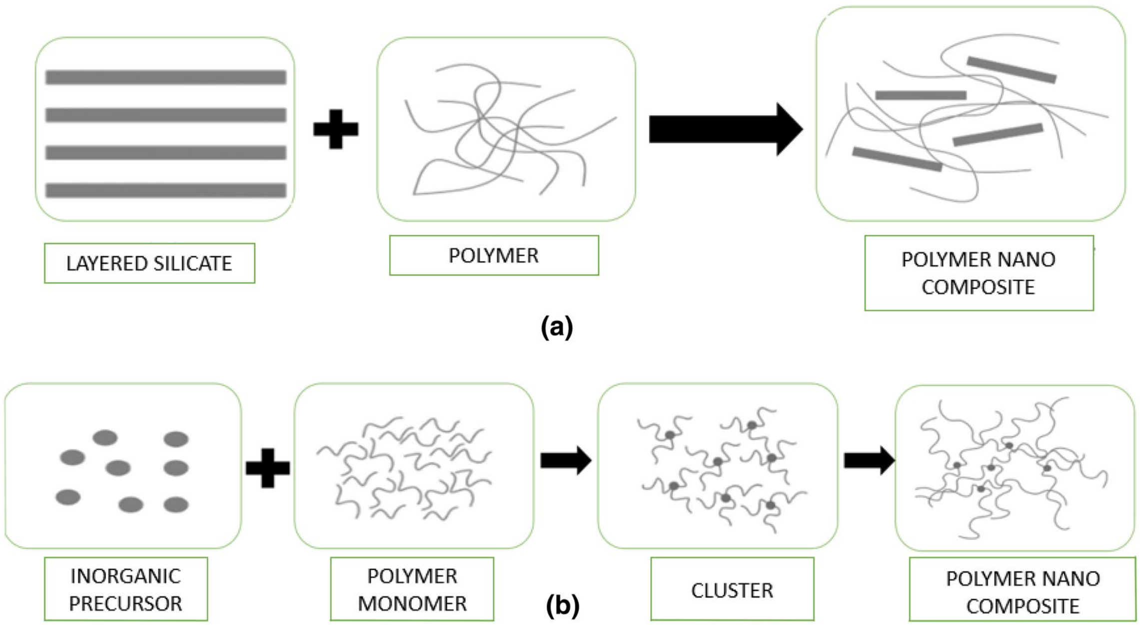

Fig. 3 Figure represents of **a** top-down and **b** bottom-up approaches

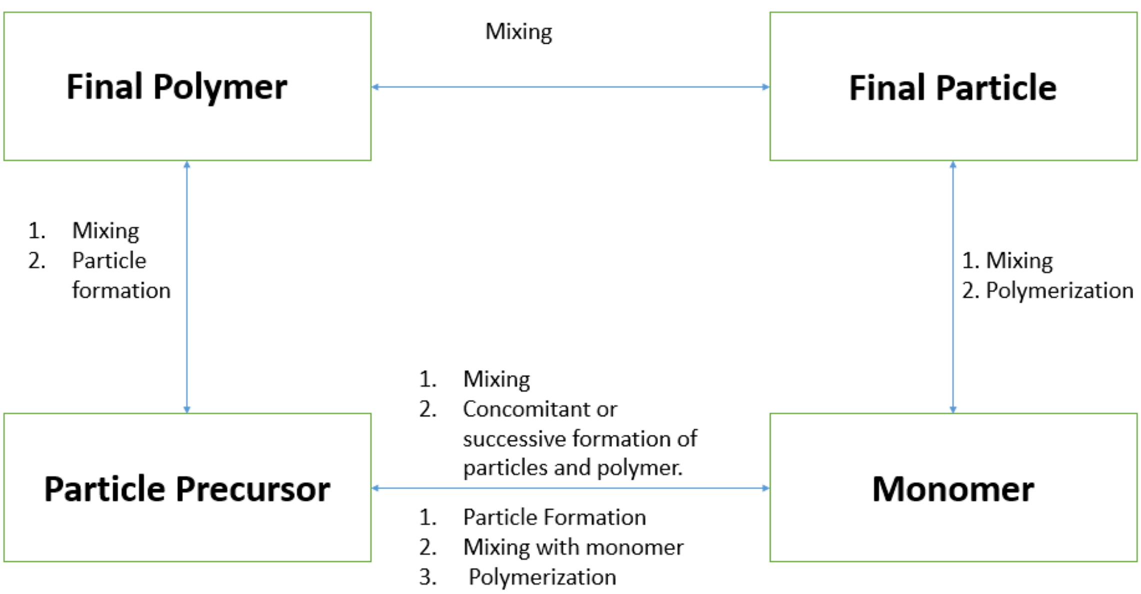

Fig. 4 Summary of nanocomposites preparation methods adopted from [45]

two inactive groups. The molecule's new periphery is then activated for reactions with additional monomers [71].

The foundation of dendrimer production is cascade reactions. The divergent technique, which was popular in the early eras, began with the innermost of the dendrimers, where the arms are connected, and proceeded to add blocks in step-by-step exhaustive manner. Synthesis in the convergent approach begins on the outside, by considering molecular structure which will eventually become the final dendrimer's outermost arm. The final generation number is predetermined in this technique, which necessitates the synthesis of branches of various sizes in advance for each generation [3].

Metals

The manufacture of n-Al can be divided into two categories: vapour-phase condensation and liquid-phase chemistry. Bulk aluminium samples' evaporation or aerosized micron-sized powders and then followed by vapour condensation in a controlled manner are two more methods for producing n-Al. Most metal nanopowders are made utilizing one or more of the same procedures used to make aluminium nanopowders. Vapour condensation techniques are made possible by intense energy sources such as lasers or arcs, which can evaporate virtually any metal. Another typical method for making metal nanopowders is to reduce different metallic complexes in solution. Nanopowders are relatively expensive in both applications, and their manufacturing is also not much wide spread. Boron powders are generally not promoted as nanoparticle [24].

The use of organisms to produce metal nanoparticles is one of the most often considered ways. Plants appear to be the best choices among these creatures, and they are well-suited to large-scale nanoparticle production. Plant-produced nanoparticles are more stable and have a higher rate of synthesis than microorganism-produced nanoparticles [38]. These type of nanomaterials are also sustainable and cause the least harm to the environment.

Review of recent works

Some recent works by researchers who have used dendrimers and iron oxide-based nanomaterials in their work are reviewed in this summary and tabular form. [25, 66] discuss the biomedical application of dendrimers. They state that dendrimers can be substitutes for blood as they possess similar properties to nanoparticles. One such example is polyamidoamine dendrimers.

(Sampathkumar et al. 2007) concentrated over the ability of dendrimers to deliver controlled and specified drug delivery, which is relevant to nanomedicine, is perhaps their [43] most promising promise. Improved pharmacokinetic qualities of cancer medicines are one of the most fundamental concerns facing modern medicine.

discusses that since their inception, biodegradable dendrimers have been regarded as attractive candidates for drug delivery due to their combination of biodegradability and dendrimer characteristics such as numerous internal voids and extensive surface functions.

Patel et. al. focuses on the fact that metal chelates based on dendrimers are used as contrast agents in magnetic resonance imaging. Because of their qualities, dendrimers are an excellent choice for image contrast media.

[29] states that PAMAM dendrimers are believed to have benefits in improving drug delivery system solubility. The unimolecular micelle characteristic of dendrimers is due to their hydrophilic exteriors and interiors. Dendrimer-based carriers have the potential to improve the oral bioavailability of difficult-to-absorb medicines. As a result, dendrimer nanocarriers have the potential to improve the bioavailability of poorly soluble medicines and/or efflux transporter substrates.

There have been numerous instances of transition metal nanoparticles enclosed in dendrimers acting as industrial catalysts. **(Gross et al. 2012)** discovered a novel homogeneous catalyst. This nanocluster catalyst is made by enclosing Au nanoparticles inside a dendrimer, and it has a high yield for catalysing the cyclopropanation rearrangement.

Discusses that dendrimers are one of the most useful non-viral gene delivery systems, and they play a key role in the development of non-viral vectors for gene delivery because of their ability to transfect cells without causing toxicity, as well as their high charge density and tunable surface functional groups, which allow optimal condensation and formation of nanostructures with DNA, known as "dendriplexes."

[62] talks about dendrimers' selective activity has been utilised to minimise the toxicity of amphotericin B in the treatment of leishmaniasis and toxoplasmosis. Dendrimers were developed as a vaccine carrier for the prevention of schistosomiasis infection, which is characterised by an IgG2a antibody response and elevated IL-2 and IFN- production in vivo. Furthermore, dendrimers have demonstrated a distinct targeting mechanism for plasmodic red blood cells compared to uninfected red blood cells in the treatment of malaria.

(Zhang et al. [90] published a paper in 2015 that described bioinspired tryptophan-rich peptide dendrimers as a new form of dendritic peptide medication for effective tumour therapy. The tryptophan residues (indole rings and amino groups) demonstrated extraordinary supramolecular interactions with DNA, and the dendrimers revealed considerable anticancer activity both in vitro and in vivo. Despite the lack of information on whether this dendrimer is biodegradable, it has paved the path for the development of new therapeutic dendrimers.

Some iron-based nanoparticles used for removal of water contamination, for gene delivery system, MRI and optical imaging, and as anticorrosive coating are summarized below in tabular form in Table 1

Challenges and future scopes

Nanoproducts are emerging as the next industrial revolution, enabling enhanced functionality of the products currently being manufactured as well as manufacturing new products with higher scopes of application. It is clear that with increasing technologies, needs and the wide area applications of nanoproducts, the demand will certainly increase.

Table 1 brief on iron oxide-based nanoparticles

Sr. no	Description of Iron oxide nanoparticle	Experimental details	Results and analysis	Reference
1	Biogenic synthesis of iron oxide-based nanoparticles for the preparation 2-arylbenzimidazole. Iron oxide nanoparticles were characterized by UV–Vis, TEM, DLS, FTIR and XRD	The desired product was obtained by mixing iron oxide nanoparticle, o-phenylenediamine, and acetonitrile	In their results TEM pictures showed nanoparticles of size below 25 nm and the 2-arylbenzimidazole formed was environmentally benign	**(Kumar et al. 2014)**
2	Super-Paramagnetic Iron oxide nanoparticles for the removal of chromium from contaminated water	Two types of materials were made SPIONs and chitosan-coated SPIONs. pH optimization, adsorbent optimization, chromium detection techniques and adsorption isotherm are various methods incorporated	From the experiment it was found that acidic pH was favourable. It was found that 10 g/l of adsorbent can efficiently remove 50 ppm of hexavalent chromium ions at pH equal to 2	[75]
3	Uses of Nano-iron oxide dispersed alkyd coating for anticorrosive coating in industrial utilities	Nanoparticle was prepared using gel combustion followed by calcination. Surface roughness, pigment characterization, FTIR, film thickness analysis, and various corrosion studies were carried out	Corrosion inhibition efficiency was found to be 89.52% for 0.1 M HCL, 97.28% for 0.1 M H_2SO_4, and 99.40% for 0.1 M HNO_3	[39]
4	Iron oxide nanoparticle in controlling RNA expression in cancer, detectable by MRI and in vivo optical imaging	Dextran T10 in powder form was used for the making of nanoparticle. MRI studies were carried out by high quality scanner, and in vivo fluorescence optical imaging were the various methods carried out	Iron oxide nanoparticle was found useful in imaging and detection. Brown and green colour crystal should be avoided for better quality of nanoparticle. Fresh solution needs to be prepared each time	**(Medarova et al. 2016)**
5	Iron oxide nanoparticle for the removal of heavy metal from contaminated water.	SEM experiment, Adsorption experiments such as effects of contact time, effect of pH, effect of metal concentrations, temperature were the studies carried out by the researchers.	Result showed that iron oxide was efficient in the removal of heavy metals such as As(III) and Cu (II) than other metals which were tested. It was found that lower pH was favorable for removal.	**(Al-Saad et al. 2012)**
6	Super-Paramagnetic nanoparticle made of iron oxide with chitosan linoleic acid for effective gene delivery system.	Nuclear and MR imaging, specific cellular uptake of nanoparticle, in vitro cell transfection, in vivo gene delivery were the various studies carried out by the researchers.	Polymeric magnetic nanoparticles used by the researchers were useful for both targeted gene transfer and hepatocyte-targeted MR imaging.	**(Cheong et al. 2009)**

With its wide application, there are various challenges while using them in different industrial branches. Firstly, the health and safety concerns which are raised because of unique physiochemical properties of nanoproducts [18]. There has been a lot of publication which highlighted on the exponential growth of the nanoproducts but the nanowaste management is still a huge concern with more usage of nanoproducts. Failure in addressing these concerns have enhanced the discharge of nanomaterials in the environment. This leads to contamination of soils, surface and ground water resources. If there is no control on the discharge knowing its side-effects, it will increase cleaning cost along with it lack of suitable technologies for remediation and finding out the contaminated areas. One of the important sector where nanoproducts are used the most is cosmetics, cosmetics constitute the largest number of nanoproduct which is more than 50% of currently available in the market [80]. With that high usage, it is more likely that nanowaste of that products will be discharged in the environment and due to that toxicity, health-related issues and contamination of water and soil will be more [64]. As the size of nanoproducts is very small, it can easily penetrate into plant and animal tissues, also having high surface to volume ratio their reactivity and toxicity increases [74]. Silver nanoparticles when used in medical application, it was found that nanoparticles induces toxicity due to release of silver particles in human lungs. This is harmful to human cell [3]. Carbon nanotube used in various application such as medical, cosmetics, electronics, sporting equipment and in food industry can cause respiratory toxicity, water contamination, seeds germinations and inflammation [88]. Moreover, the cost of such nanoproducts is also very high; along with it, the reuse of waste nanoproducts should be enhanced. Developing nanoproducts have challenges like developing power system with higher efficiency and with keeping in mind the size factor. Insufficient data, infrastructure and facilities are also important factors in developing nanoproducts. More investment and funding should be provided in order to scale up the production [27]. To overcome the toxicity factor and the health-related issues arising due to the discharge of nanomaterials, environmental friendly nanoproducts are produced which will eliminate the toxicity in water resources and soil contamination. There are numerous future aspects and research areas related to developing green and sustainable nanoproducts.

Nanomaterials' limitless potential has already had a significant impact on human lives. However, the potential negative effects of nanomaterials on human health and the environment have always been a source of concern. Concerns about the safety of nanoparticles in terms of human health and the environment have prompted the development of green nanotechnology, which combines green chemistry concepts with nanotechnology. Many of the severe problems of nanotoxicology could be addressed using green nanotechnology in the long run. Material synthesis design improvements and careful handling could greatly increase safety levels. Safer products have been designed using green chemical techniques, which are capable of reducing the raw materials required in the manufacturing process; along with it, harmful chemicals, the energy usage and production cost can also be reduced. By studying safer and biocompatible raw materials, green and sustainable products can contribute to develop green and eco-friendly nanoproducts having better chemical and physical properties than the existing ones. It could pave the way for the creation of a well-defined nanomaterial with high purity. Using biomass to make nanoparticles could be an excellent waste management option. Another factor to consider is the marketing of new non-toxic nanomaterials while assuring their material safety. Green chemistry can affect nanofabrication processes by allowing for more efficient creation of greener nanomaterials with a better throughput. Another future perspective to consider is optimizing production environment conditions for better and efficient nanomaterial manufacturing approaches, and if we are successful in doing so it can lead to more and more investment in nanoindustries by demonstrating nanomaterials' limitless potential without troubling people away from them [8]. Future perspectives are shaped by new scientific ideas and by current societal challenges such as environmental regulations, the need for increased innovation and sustainability in industrial processes, and the need to reduce ecological biodiversity loss caused by pollution and climate change.

Conclusion

From our review and recent research in this field, it is very clear that green nanomaterials are very useful in different sectors, they can be used in the removal of water contamination, gene delivery system, optical imaging, anticorrosive coating and many more can be found with advances in research works. Growing frameworks of sustainability criteria for producing green nanomaterials is a challenge that requires methodological rigour, and proper planning in order to match the sustainable growth requirements. For the nanotechnology to be sustainable, the waste from nanoproducts should be managed effectively. We have classified various types of consumer nanoproducts in this review, which in turn have their own specific use in different sectors. We have discussed about the synthesis of various nanoproducts. Along with it we have also emphasized on the challenges faced by current nano-industries, like toxicity environmental issues, health issues and soil contamination. Future scopes in enhancing nano-industry, developing green and sustainable nanoproducts are also incorporated. The need of the hour is to make the synthesis process more and more environment friendly by optimizing the process and minimizing the waste making it utmost favourable to environment. Assessment of environmental impacts for the usage of nanoproducts is required, proper emphasize on the organization of the supply chain and increasing the area of its application, and these are the areas which can enhance the use of nanoproducts keeping in mind the environmental concerns. Further, researchers should focus more on developing engineered nanomaterials which in turn have less environmental impacts.

Acknowledgements The authors are grateful to Department of Chemical Engineering, Pandit Deendayal Energy University, for the permission to publish this research.

Authors contribution All the authors make a substantial contribution to this manuscript. DS, RB and MS participated in drafting the manuscript. DS, RB and MS wrote the main manuscript; all the authors discussed the results and implication on the manuscript at all stages.

Availability of data and material All relevant data and material are presented in the main paper.

Declarations

Conflict of interests The authors declare that they have no competing interests.

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