Green Nanomaterials for Clean Environment

3

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Contents

Abstract

Current improvements in nanotechnology and nanoscience have also led to the development of novel nanomaterials, which eventually increase possible health and environmental threats. Moreover, many researchers are interested to develop environmentally benign processes for the preparation of metal and metal oxide nanoparticles which has been improved. The main determination is to reduce the destructive influences of synthetic processes, their associated chemicals, and derived complexes. The use of different biomaterials for the preparation of nanoparticles is measured a valuable methodology in green nanotechnology. In addition, a favorable method to reach this objective is to utilize the biological properties in nature through a range of activities. Actually, over the previous decades, algae, plants, bacteria, fungi, and viruses have been used for construction of energy-efficient, low-cost, and nontoxic metallic nanoparticles. The recent interest in nanomaterials is attentive on the manageable properties (shape and

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size) because the electronic, optical, magnetic, and catalytic properties of metal nanoparticles mainly depend on their sizes and shapes. Such exclusive features of nanostructured materials can be more tailored and plotted to a specific energy and environmental challenge.

Introduction

The "green" eco-friendly procedures in chemistry and chemical technologies are attractive progressively and are much desirable worldwide with less difficulties related with ecological worries. Nanotechnology has ability to quantify, visualize, operate, and manufacture things on an atomic or molecular scale, regularly among 1 and 100 nm [1]. These tiny yields have a huge surface area to volume ratio; for this reason, noble metal nanoparticles like gold, silver, platinum, palladium, etc. and nonmetallic, inorganic oxides like zinc oxide and titanium oxide have been extensively used in biotechnology, optics, mechanics, electronics, microbiology, environmental remediation, medicine, many engineering fields, and material science [2, 3]. Normally, during this phase of improvement of a new technology area, scientists focus essentially on classifying new assets and applications. As a result, the investigation of any unintended properties of the material (e.g., environmental or health hazards) or concerns about hazards or adeptness of the production procedure is often delayed. In addition, the predictable extensive application and distribution of these materials in trade and attention of the materials design, processes, and applications that minimize hazard and waste will be vital as nanoscience discoveries convert to commercialized products of nanotechnology [4]. In the synthesis of nanoparticles, there has been an increase in the expansion of healthy and eco-friendly techniques which don't need the utilization of the toxic chemicals. Additionally, the growth of metal nanoparticles using chemical or physical procedures is not gracious or healthy with the use of reducing agents which are extremely reactive or toxic in nature for human consumption or to the environment, and these are also relatively expensive for upscale preparation [4]. The green synthesis contains microorganisms as reducing agents like fungi, algae, bacteria, virus, and plants, which are known as the "bio-nano factories" as they are ecologically active, affordable, individually structured, macroscopic, and great in metal application [5–7].

Nanotechnological products, methods, and applications are estimated to contribute significantly to eco-friendly and climate protection by saving raw materials, energy, and water as well as by decreasing greenhouse gases and dangerous wastes. Therefore, the use of nanomaterial has shown good abilities in definite environmental benefits and sustainability properties [8]. But, nanotechnology plays a relatively subordinate role in environmental protection, whether it be in research or in practical applications. Eco-friendly engineering companies themselves attach only limited importance to nanotechnology in their respective fields. In addition to providing enriched research and growth policies, green chemistry proposals, and chance to improve public awareness of nanoscience, this method is comparatively easy to describe and can be used to transfer a responsible attitude to the improvement of this novel technology [9, 10]. Green chemistry can play a prominent administrative role in the development of nanotechnology to afford the extreme assistance of these products for the society and the environment. Moreover, green chemistry is the employment of a set of principles that decreases or removes the use or group of hazardous materials in the design, production, and application of chemical products [11, 12]. The principles of green chemistry (initially well-defined by Anastas and Warner and summarized in Table 1) have now remained applied to the design of a wide range of chemical products and methods with the aims of reducing chemical hazards to health and the environment, reducing waste, and preventing pollution. Employing these principles to nanoscience will simplify the manufacture and processing of essentially safer nanomaterials and nanostructured devices [13, 14].

Chemical corporations envision renewable feedstocks given a financially stable source of starting material. With such a huge portion of initial materials coming from oil, chemical companies are particularly exposed to variations in crude oil prices. Moreover, consumers are gradually selecting naturally derived products for their perceived safety and environmental benefits. Petrochemical feedstocks provide very simple hydrocarbons, which chemists have learned to make more complex. Natural feedstocks are inherently different. They are complex molecules, and chemists are still developing graceful ways to capably transform them into useful products [15]. The idea of a biorefinery, which could take biomass and postconsumer waste and turn it into fuels [16] and other chemical products [17], has been suggested by several researchers as a significant path toward chemical sustainability. Figure 1 outlines the possible materials flow through a biorefinery. Like a traditional petroleum refinery, a biorefinery maximizes materials utilization through many parallel processes. An ideal biorefinery uses all input mass to produce biofuel or chemical feedstock material. Researchers are putting forward continuous efforts to improve facile, active, and reliable green chemistry methods for the preparation of nanomaterials. A number of organisms act as clean, environmental, and sustainable precursors to produce the steady and well-functionalized nanoparticles. These could contain fungi, bacteria, actinomycetes, viruses, yeast, etc. Therefore, it is extremely significant to discover a new reliable and sustainable method for the preparation of nanomaterials [14]. Environmental sustainability, economic viability, and social adaptability as well as the accessibility of local resources are a matter of concern in the manufacture of nanomaterials (Fig. 2).

Green nanotechnology contains application of green chemistry principles to the design of nanoscale products, enlargement of green nanomaterial production procedures, and application of green nanomaterials (Fig. 3). This method aims to change an understanding of the properties of nanomaterials, including those related to toxicity and especially ecotoxicity, and to design nanoscale materials that can be combined into high-performance products that are safer to human health and the environment [18].

Green Nanotechnology

Nanoparticles can be manufactured using a wide range of techniques including physical, chemical, biological, and hybrid techniques (Fig. 4) [2, 3]. The invention of nanoparticles through conventional physical and chemical procedures

Table 1 Example relationships among guiding principles for a green economy and the opportunities and challenges for nano-applications

(P1)	Is a means for achieving sustainable development
(P2)	Creates decent work and green jobs
(P3)	Improves governance and the rule of law – by being inclusive, democratic, participatory, accountable, transparent, and stable
(P4)	Is equitable, fair, and just – between and within countries and between generations
(P5)	Reduces poverty and increases well-being, livelihoods, social protection, and access to essential services
(P6)	Protects biodiversity and ecosystems
(P7)	Is resource and energy efficient
(P8)	Respects planetary boundaries or ecological limits or scarcity
(P9)	Uses integrated decision-making
(P10)	Internalizes externalities
(P11)	Measures beyond gross domestic product indicators and metrics
Example opportunities for nano-applications in a green economy (and the related principles)	
Energy conversion and storage	Smart energy nanotechnology can improve power delivery systems to be more efficient, reliable, and safe (P1, P2, P5)
	Nano-devices may trade on renewable energy produced through naturally replenished resources, i.e., sunlight and wind. This may reduce fossils as energy resources and the impact for the greenhouse gas emission balance (P3, P4, P5, P6, P7, and P9)
	Energy-efficient nanotechnology requires less energy to perform the same function – getting more use out of the already created energy (P7, P8, and P10)
Water cleanup technologies	Designed nano-enabled infrastructure necessary to manage water and keep it clean is inextricably linked to prospects for economic development and better livelihood conditions (P1, P2)
	Access to clean water and adequate sanitation is a basic human right and is critical to the alleviation of poverty (P3, P4, and P5)
	Investment in infrastructures and considerable greening of water policies is necessary to reduce the cost to face water shortages (P8, P9, P10, and P11)
Construction industry	Nanotechnology aims to increase the efficiency building's used resources – energy, water, and materials – while reducing building impacts on environment and human health through better siting, design, construction, and removal (P1, P2, P6, P7, P8, P10, and P11)
	NMs applied to the surfaces of structural elements of the buildings can contribute to environmental cleaning by photocatalytic reactions (P1, P2, P6, P7, and P8)
Other applications	Nano-enabled applications may provide a slow release and dosage of fertilizers and an efficient water reservoir for plants. This may contribute to a greater agricultural productivity, especially in countries with prolonged dry spells (P1, P2, P4, and P5)
	Nano-packaging – with improved barrier and mechanical properties – may allow a longer safe storage of food, especially in regions where cooling is not easily available (P2, P4, P5, and P8)

(*continued*)

Table 1 (continued)

	Nano-sensors may improve the quality and reduce the cost of continuous environmental monitoring. Nano-remediation of environmental pollution may exceed conventional methods in efficiency and speed (P1, P2, P6, and P7)
Practical challenges for nano-applications in a green economy	
Technical	Efficient synthetic pathways must be developed to obtain NMs "safe by design" (e.g., through green chemistry, optimized reaction chemistry, minimized energy consumption and costs, employment of benign feedstocks and reagents, avoidance of hazardous substances and pollutants)
	Analytical methods must be developed to obtain a reliable nanomaterial characterization and tools to detect, monitor, and track NMs in the environment and biological media
Biological	Biological impact must be determined for NM primary and acquired physicochemical properties (size, surface area, chemical composition, protein corona as a nano-biointeraction) on ecosystems, as well as in in vitro and in vivo models
	The "life-cycle" impact must be assessed for NMs on the environment and biological systems: NMs emitted from production processes or released from nano-enabled devices during their assembly, use, recycling, or disposal
Health and safety	NM key health effects must be defined: e.g., pulmonary toxicity, genotoxicity, and carcinogenicity
	Information must be developed on the potential toxicity of NMs available for employers and workers involved in NM research and developmental areas, as well as in nano-enabled device manufacture, assembly, application, and disposal, avoiding dispersion of essential information
	A highly skilled workforce must be built and sustained that is well trained to face emerging risks as well as known physicochemical risks in new situations and also trained to avoid accidents
Public and occupational policies	Participation of scientific, governmental, industry, and workforce representatives must be pursued for the processes of opinion forming, education, and decision-making in shaping green nanotechnology
	Nano-green jobs must redirect current path of environmental decline and create economic opportunity, strengthening local urban and rural communities
	The green economy policies must balance nanotechnology environmental, societal, and occupational and health promotion benefits, with commercialization costs and risks
	Companies involved in green-nanotechnology innovations must plan a precautionary risk management approach by identifying actual risks and planning/implementing control measures and risk communication

results in toxic by-products that are environmental hazards. Furthermore, these particles cannot be used in medicine due to health-related issues, especially in clinical fields [19]. Conventional techniques can be used to synthesize the nanoparticles in huge quantities with definite sizes and shapes in a shorter period

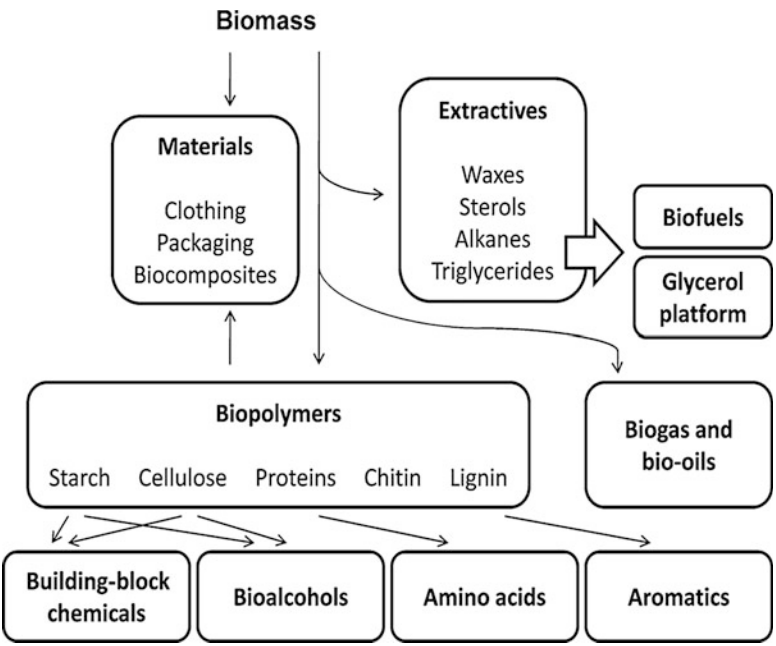
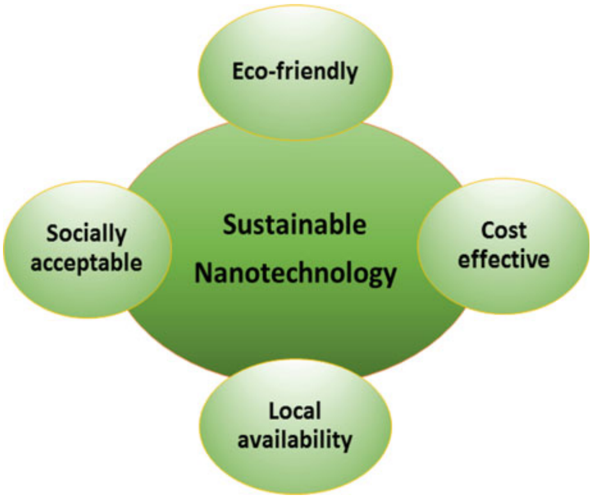


Fig. 1 The materials flow from biomass green synthesized material to final products or chemical feedstocks

Fig. 2 Sustainable green nanotechnology



of time; though, these methods are complicated, costly, inefficient, and outdated. In recent years, there has been rising attention in the preparation of environmentally friendly nanoparticles that do not produce toxic waste products during the manufacturing process [20]. In addition, this can only be attained through benign

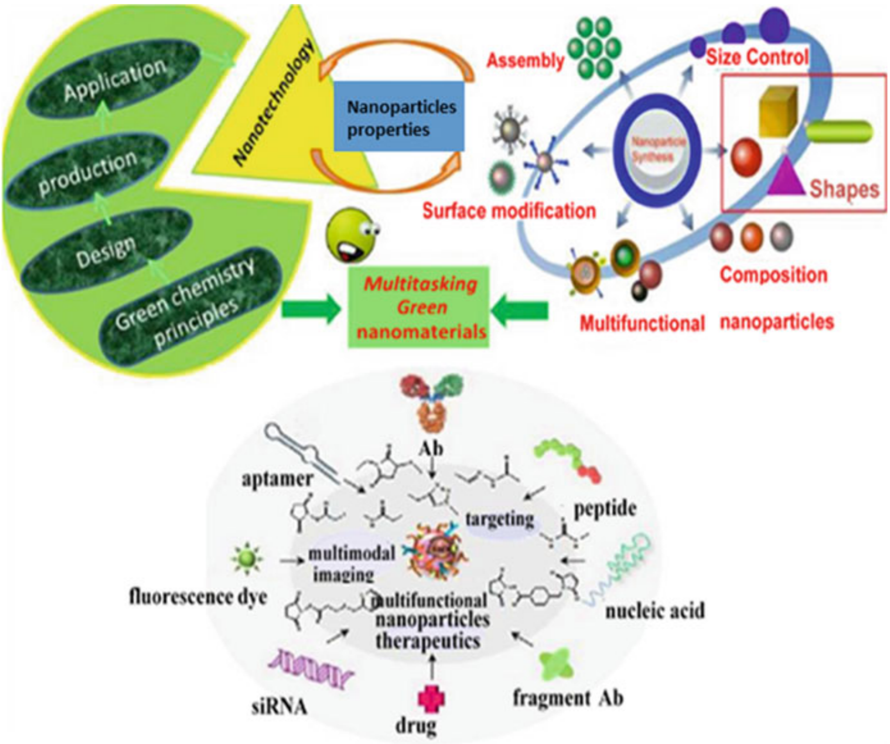


Fig. 3 Schematic illustration of multifunctional nanoparticle

synthesis processes of a biological nature using biotechnological tools that are considered safe and ecologically sound for nanomaterials fabrication as another to conventional physical and chemical techniques [21]. This has been specified and increased to the concept of green technology or green nano-biotechnology. Biological-based production of nanoparticles utilizes a bottom-up approach in which preparations occur with the help of reducing and stabilizing agents (Fig. 5).

Three main steps are monitored for the preparation of nanoparticles using a biological system: the choice of solvent medium used, the choice of an eco-friendly and environmentally benign reducing agent, and the choice of a nontoxic material as a capping agent to steady the manufactured nanoparticles [3]. Additionally, nanotechnology has more advantages over other straight methods owing to the availability of more components by biological system for the formation of nanoparticles. The rich biodiversity of such biological components has been explored for the synthesis of bio-nanomaterials, which are ecologically benign and can be used in various medical applications.

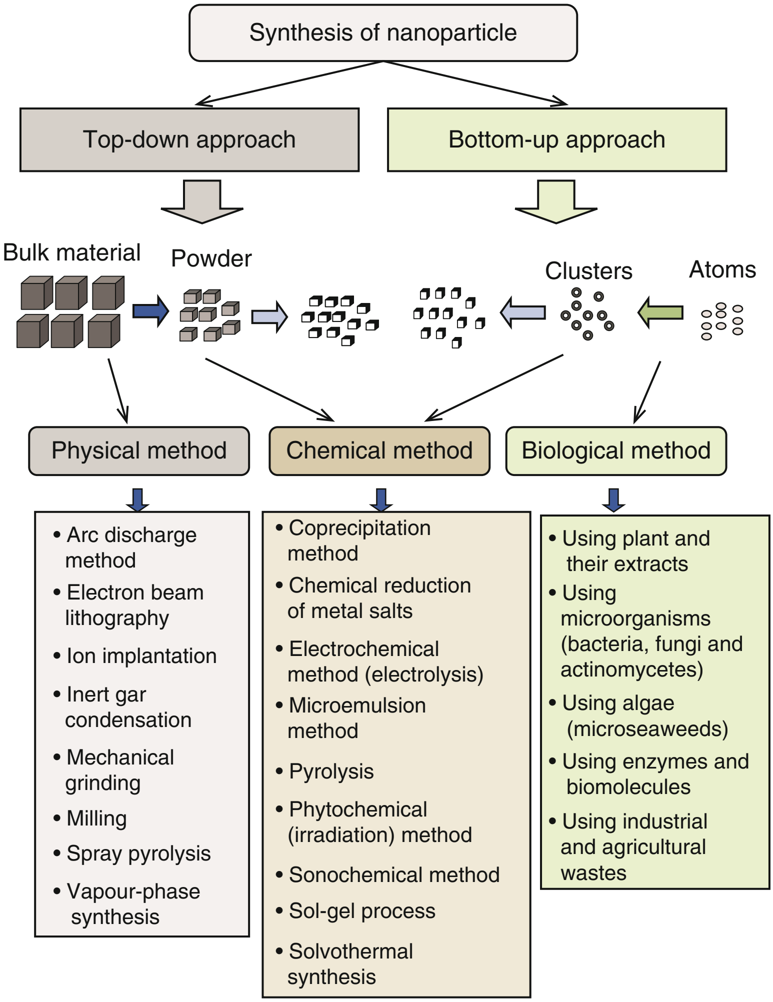


Fig. 4 Different approaches and methods for synthesizing nanoparticles

Potential Environmental Benefits for Green Synthesis Nanoparticles

Increasing prices for raw materials and energy, united with the increasing ecological awareness of users, are responsible for a flood of products on the market that have potential positive benefits for ecological and climate protection. Nanomaterials display superior chemical and physical properties that make them exciting for novel, environmentally friendly products [22], for example, increasing robustness of materials against mechanical stress or survival; assisting to increase the suitable life of

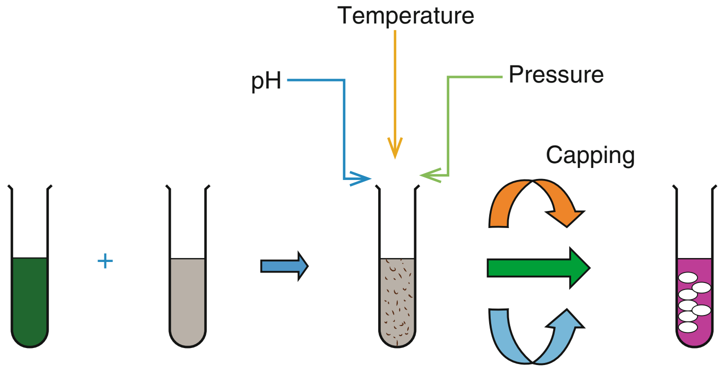


Fig. 5 Biological metal reduction synthesizing extract solution reaction to stabilize green technology

a product, nanotechnology-based dirt- and water-resistant coatings to decrease cleaning efforts, and novel lining materials to improve the energy effectiveness of buildings; and adding nanoparticles to a material to decrease weight and save energy during transport [23]. Moreover, in the chemical production sector, nanomaterials are useful based on their different catalytic properties in direction to boost energy and source efficiency, and nanomaterials can replace environmentally problematic chemicals in definite fields of application. Extraordinary expectations are being placed in nanotechnologically enhanced products and procedures for energy assembly and storage; these are present in the improvement phase and are slated to give significant environment protection and solve energy problems in the future. In maximum commercially existing "nano-consumer products," environmental protection is not the main goal [24].

Nanotechnology Might Make Battery Recycling Economically Attractive

Batteries are an essential part of present life – just go ahead and count the batteries that we use in our cell phones, watches, computers, alarm clocks, cameras, toys, flashlights, remote controls, cars, power tools, boats, and so on. In addition, less chances are that our batteries are disposable; hence we throw them out with your garbage when they are empty. Moreover, many batteries are used by hospitals, industry, public transport, the military, etc., and we get some billion batteries that are bought every year, a roughly $50 billion market.

A number of batteries contain heavy metals such as lead, mercury, cadmium, and nickel, which can contaminate the environment and pose a possible threat to human health when batteries are incorrectly disposed into the environment. Not only do the billions upon billions of batteries in landfills pose an environmental problem, but they also are a complete waste of a potential and cheap raw material. The economic

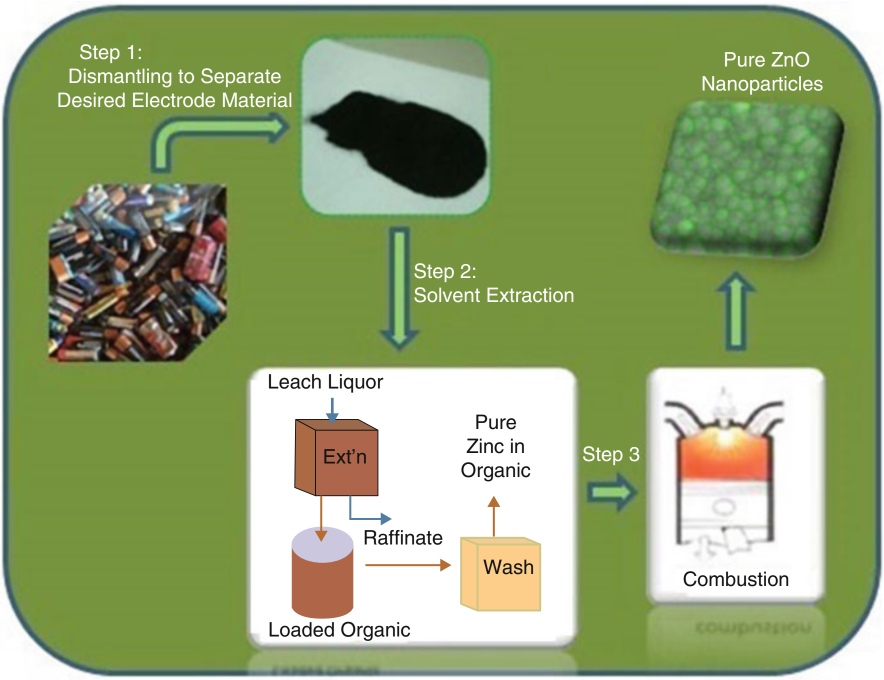


Fig. 6 Scheme for the recovery of pure zinc oxide nanoparticles from spent Zn-Mn dry alkaline batteries

recycling problem is mainly serious in developing countries such as African and Asian countries where, therefore, economic interests supersede environmental responsibilities. The recovery of zinc oxide nanoparticles was showed in Fig. 6.

Nanomaterials for Radioactive Waste Cleanup in Water

Radioactive waste that contains radioactive material is dangerous to human health and the environment and is controlled by government agencies in order to protect human health and the environment. Based on the several applications of nanotechnology that have environmental implications, remediation of polluted groundwater using nanoparticles containing zero-valent iron (nZVI) is one of the best prominent models of a fast developing technology with significant benefits. In 2008 many researchers described on nanotechnology solution for radioactive waste cleanup, especially the use of titanate nanofibers as adsorbent for the elimination of dangerous radioactive ions from water. Nowadays, researchers have developed green synthesis-based nanomaterials and reported these materials (titanate nanotubes and nanofibers) have exceptional structural properties for novel applications and make them as more suitable materials for the removal of radioactive cesium and iodine ions in water.

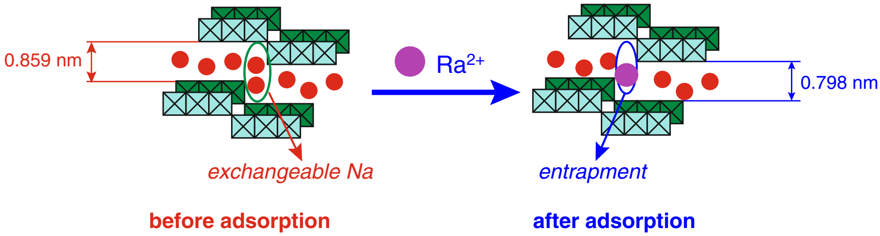


Fig. 7 Scheme for the removal of the radioactive ions through ion exchange and structure deformation

Moreover, in order to release and immobilize iodine ions from water, the researchers has anchored green synthesis-based silver oxide nanocrystals on the outer surfaces of titanate nanotubes and nanofibers by chemical bonds due to their crystallographic similarity. These mixtures can powerfully capture iodine ions, forming silver iodine precipitate on the titanates. The schematic illustration on the removal of radioactive ion exchange was displayed in Fig. 7. Furthermore, carbon nanotubes, fullerene, and metal-based nano-adsorbents can offer significant developments in the adsorption capacity of organic molecules, metal ions, and heavy metals [25, 26]. Green synthesis-based nanomaterials showed unique electrochemical, optical, and magnetic properties. Active research is going on to develop performance enhanced nano-enabled pathogen sensors, both cells and biomolecules [27]. A potential "on-demand" release policy is to summarize antimicrobial agents into a matrix gated by materials reactive to the presence of microorganisms or biofilms. In addition the "on-demand" mechanism can be further attached with recognition mechanisms for targeted release (see Fig. 8). For green synthesized nanomaterials relying on direct contact, catching may largely suppress or even remove their antimicrobial activity.

Nanomaterials for Energy Conversion and Energy Storage

The use of nanomaterials in energy exchange and storage signifies a chance to increase the performance, density, and ease of transportation in renewable resources. As is true in various other fields, the expansion of energy conversion and storage technologies axes on the accessibility of appropriate resources. Everybody knows that the most exciting and most flexible renewable energy technologies are the direct change of sunlight into electric power: the photovoltaic effect [28]. Moreover, the carbon nanomaterials, containing C_{60} fullerenes, carbon nanotubes, and graphene, have been studied as very effective electron acceptors in polymer and quantum dot solar cells [29–31]. In addition to solar cells, green nanotechnology has big impact on fuel cells, devices able to convert chemical energy directly into electricity. Mainly, the nano-porous metals with high surface area, low specific densities, and rich surface chemistry can act as a highly efficient electro-catalyst

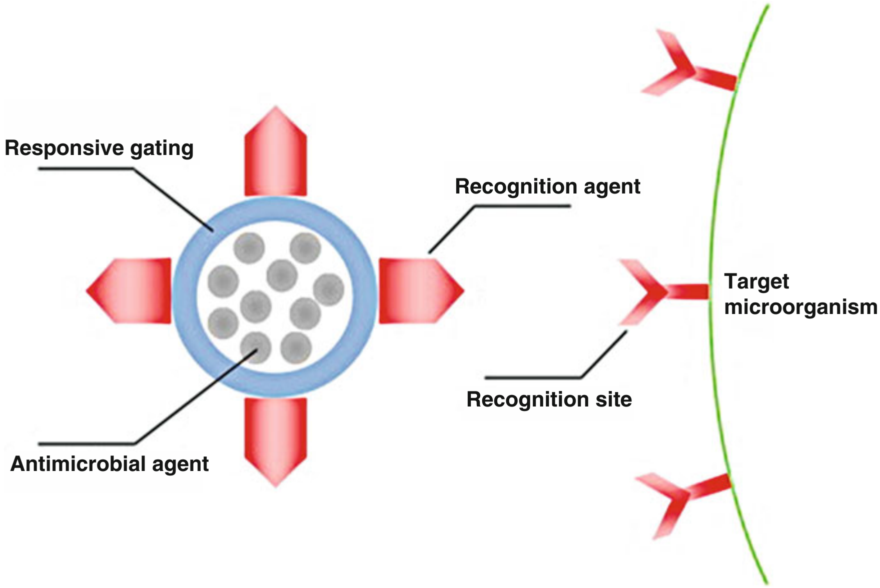


Fig. 8 Schematic illustration for "on-demand" microbial control. "On-demand" microbial control can be achieved by using recognition agents that target specific microorganism. The responsive gating material is designed to release the antimicrobial agent after the recognition event

for the critical electrode oxidation/reduction reactions in fuel cells [32]. Another significant future energy option is the hydrogen gas as an endless source of clean fuel for various applications. Semiconductor nanomaterials, e.g., TiO_2 and cadmium sulfide nanostructures, have been studied as effective catalysts for water conversion into oxygen and hydrogen [33, 34]. Furthermore, nanostructured carbons, metal-organic frameworks, and polymers as well as metal hydrides and related complex hydrides are models of investigated nanomaterials for hydrogen storage and transportation for high hydrogen capacity and minimal deterioration during hydrogenation [35, 36]. Nanotechnology have showed deep influence on electrical storage technologies, i.e., batteries and electrochemical supercapacitors. Redox-based supercapacitors with nanostructured electrode materials have exposed the potential to combine the high energy density of conventional batteries with the high power capabilities of electrostatic capacitors at the lab scale. In addition mixed metal oxides, e.g., manganese oxide (MnO_2), ruthenium oxide (RuO_2) [37, 38], magnetite (Fe_3O_4), carbon nanotubes, graphene, and carbon-metal oxide composites, have been examined as electrode nanomaterials designed at a high specific capacity and rate capability. In addition the reduced dimensions and high surface area of nanomaterials increase the rate of electron transport and the electrode-electrolyte contact, respectively, while the nanostructure itself offers facile strain relaxation and resistance to fracture. However, emerging interests have been focused on metal oxide green synthesized nanoparticles, e.g., SnO_2, TiO_2, or $LiFePO_4$ nanomaterials, for anode or cathode applications [39, 40].

Nanomaterials for Construction Industry

In nanotechnology applications in biomedical and electronic industries, the construction industry newly started looking for out a way to advance conventional construction materials using a variety of manufactured nanomaterials. The use of nanotechnology materials and applications in the construction industry should be considered not only for enhancing material properties and functions but also in the context of energy conservation.

In addition the basic construction materials cement, concrete, and steel will also benefit from nanotechnology. Nanoparticles will lead to stronger, more tough, self-healing, air-purifying, fire-resistant, easy-to-clean, and quick-packing concrete. Furthermore, some of the nanoparticles that could be used for these features are nano-silica (silica fume), nanostructured metals, carbon nanotubes, and carbon nanofibers. The possibility to commercialize nanotechnology for green invention has become a specific focus of attention in recent years as nanotechnology research starts to be used in several concrete applications. Due to the rising energy scarcity as well as global warming, countries are now paying much closer attention to clean energy technologies and using green technology in industry [41]. In addition a new industrial ecology might arise if nanomaterials made by green synthesis replaced present materials in products, if new products were designed using green engineering principles, and if cleaner nano-based manufacturing processes were adopted [42]. Moreover, tailing after developing nanotechnology applications in biomedical and electronic industries, seeking out a way to advance conventional construction materials using a selection of manufactured nanomaterials (Fig. 9) [43]:

Carbon nanotubes – Normal benefits are mechanical strength and crack prevention (in cement), improved mechanical and thermal properties (in ceramics), real-time structural health monitoring, and active electron mediation (in solar cells).

Silicon dioxide nanoparticles (SiO_2) – The ordinary assistances are strengthening in mechanical strength (in concrete); coolant, light transmission, and fire resistance (in ceramics); and flame-proofing and anti-reflection (in windows).

Titanium dioxide nanoparticles (TiO_2) – The expected uses are fast hydration, increased degree of hydration, and self-cleaning (in concrete); superhydrophilicity, antifogging, and fouling-resistance (in windows); and nonutility electricity generation (in solar cells).

Iron oxide nanoparticles (Fe_2O_3) – The ordinary benefits are enlarged compressive strength and abrasion-resistant in concrete.

Copper nanoparticles – The expected uses are weld ability, corrosion resistance, and formability in steel.

Fig. 9 Examples of manufactured nanomaterials used by the construction industry. (**a**) Rooftop solar panel. (Source: National Renewable Energy Laboratory (NREL)). Inset: Arrays of silicon/TiO_2 nanowires. (Source: Lawrence Berkeley National Laboratory (LBNL)). (**b**) Concrete pavement. Inset: Carbon nanofibers. (Source: US Department of Transportation Federal Highway Administration). (**c**) Steel bridge. (Source: California Department of Transportation). Inset: Copper nanoparticles. (Source: Air Force Research Laboratory). (**d**) Building window. (Source: LBNL). Inset: TiO_2 nanoparticles

Silver nanoparticles – The normal benefits are biocidal activity in coatings and paints.
Quantum dots – The expected advantages are effective electron mediation in solar cells.

Benefits and Limitations of Green Nanotechnology

While nanotechnology is seen as the way of the future and is a technology that many people think, that will bring maximum benefits for all who will be using it, nothing is ever perfect, and there will always be pros and cons to everything. The advantages and disadvantages of nanotechnology can be easily enumerated, and here are some of them; these application areas are assessed relative to their scale and scope through market forecasts, green benefits, and potential issues and limitations [44]. The main advantages are that it uses renewable resources that never reduce in nature. That means future generation can benefit from them too without harming the planet. Nanotechnology can also benefit the energy sector. The development of more effective energy-producing, energy-absorbing, and energy storage products in smaller and more efficient devices is possible with this technology. Such items like batteries, fuel cells, and solar cells can be built smaller but can be made to be more effective with this technology. Waste production management offers solution for waste removal and recycling and reduces the effect of global warming by minimizing CO_2 emissions. Additionally, it brings economic benefits to certain areas (farming) by increasing productivity. When tackling the advantages and disadvantages of nanotechnology, it is also necessary to point out what can be seen as the negative side of this technology, some of the disadvantages mentioned below; as the technology is being established, more efforts are being made to find ways of assessing or tracking the impact of nanotechnology on specific policy objectives such as green growth. This is a very challenging task. The risks of using new green nanotechnologies need to be considered relative to the risks in using current technologies and valued against the human and environmental costs of not effectively addressing key global challenges [45]:

- High implementing cost
- Lack of information (no clear data to what extent research organizations, universities, and companies are doing on this)
- No known alternative chemical or raw material inputs
- No known alternative process technology
- Uncertainty about performance impacts
- Lack of human resources and skills

Conclusions

Nanotechnology has been established to attain the purpose of preserving environmental sustainability. In this case, environmental sustainability is partial not only to human environmental issues but also human health problems. Moreover, technologies that have been advanced contain technologies which can increase and improve the conventional technological capabilities and new technologies which replace the conventional technologies. Therefore, in terms of environmental sustainability, the technology industries are embracing change. This technology is moving to avoid negative consequences or to meet green demand or to achieve both. Whatever the motivation, they are incontrovertibly shifting toward green synthesis. Through the introduction of this knowledge on sustainable growth, preservation of nature, conservation of human population and other living beings, and elimination of wastage and reusability, innovation and potential of present technology is made more effective manner. Nanotechnology can also be applied to avoid the increasing pollution in several metropolitan cities across the world. Green nanotechnology based applications include, synthesis of green materials, coatings, and biocides to prevent the release of hazardous substances into the environment. While nanotechnology has many applications in the fields of environmental technology, it needs to be examined further to measure its risk. This is in agreement with the principle that the more refined the green nanotechnologies, the greater the risks they pose.

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