Green Nanotechnology: The Solution to Sustainable Development of Environment

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Abstract

The environment is undergoing constant degradation in terms of quality as well as quantity due to various developmental activities occurring for satisfaction of the growing population's needs. Nanoparticles have been existing in the environment since millions of years and also being utilized since thousands of years in many areas due to their ability to be synthesized and manipulated. Literature has shown the ability of nanoparticles for detoxification of environment with respect to their usage in wastewater treatment, dye degradation, etc. However, the conventional physical and chemical methods have also shown to affect environment as it involves use of toxic substances. Hence, the green nanotechnology has gained considerable interest in recent times as an eco-friendly alternative technology for nanotechnology products. This review highlighted the characteristics, goals, and various issues in concern, of this potential field as an ultimate solution for sustainable development of environment.

Keywords

Green chemistry • Nanoparticles • Sustainable development • Wastewater treatment

1 Introduction

The natural environment consists of physical and biological factors along with their chemical interactions that affect all living and nonliving things. It has been undergoing constant changes with growth of human civilization, which has led to the deterioration and pollution of the environment through depletion of resources like air, water, and soil, destruction of ecosystems, and extinction of wildlife (Johnson et al.

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Nanoparticles have attracted considerable attraction due to their unusual and fascinating properties over their bulk counterparts for various applications, and nanotechnology involves the engineering of functional systems at the atomic or molecular scale (Hasna et al. 2012), i.e., projected ability to construct items using techniques and tools to make complete, high-performance products. Nanotechnology has a vital role in the development of innovative methods for manufacture of new products, substitution of current equipments of production, and reformulation of new materials and chemicals possessing improved performance characteristics that would result in less consumption of energy and materials and reduce harm to the environment as well as aid in environmental remediation, thus giving possibilities to remediate problems associated with the current processes in a more sustainable manner.

Environmental applications of nanotechnology answer to questions pertaining to the development of solutions to the existing environmental issues, preventive measures for future problems resulting from the interactions of energy and materials with the environment, and possible risks, if any, posed by nanotechnology itself (Mansoori et al. 2008). The environmental impact of nanotechnology can be viewed with respect to energy applications of nanotechnology and also on the influence of nanochemistry on wastewater treatment, air purification, and energy storage devices (Zhang 2003; Hillie and Hlophe 2007; Tian et al. 2007). The broader environmental impacts of nanotechnology also need consideration which include the environmental impact of the cost, size, and availability of advanced technological devices, models to determine potential benefits of reduction or prevention of pollutants from environmental sources, potential new directions in environmental science due to advanced sensors, effect of rapid advances in health care and health management as related to the environment, impact of artificial nanoparticles in the atmosphere, and impacts for the development of nanomachines (Hutchison 2001). Early application of nanotechnology having environmental implications includes the use of zerovalent iron for remediation of soil and water contaminated with chlorinated compounds and heavy metals which proves to be a rapidly emerging technology with potential benefits. Environmental remediation involves degradation, sequestration, and other related approaches that would result in reduced risks to human and environmental receptors posed by different types of contaminants, the benefits of which would be more rapid and cost-effective cleanup of waste (Mansoori et al. 2008). Minimizing quantities and exposure to hazardous waste to air and water and provision of safe drinking water are among the prominent goals of environmental protection agencies, where nanotechnology could play a pivotal role in pollution prevention technologies (Ahmadpour et al. 2003; Shahsavand and Ahmadpour 2004; Darnault et al. 2005). Though the conventional physical and chemical methods are more popular for manufacture of nanotechnology products, they face the demerit of being environmentally toxic, and it is at this juncture where green nanotechnology gains prominence due to eco-friendliness, which incorporates goals and principles of green chemistry and green engineering.

2 Green Nanotechnology

Green nanotechnology involves the development of clean technologies to minimize potential environmental and human health risks associated with the manufacture and use of nanotechnology products and to encourage replacement of existing products with new nanoproducts that are more environmentally friendly throughout their life cycle (Schmidt 2007). It emphasizes the use of nanotechnology to uplift the environmental sustainability of processes that are currently exhibiting negative effects and primarily about making green nanoproducts and using them in support of sustainability. It has two main goals:

1. *Production of nanomaterials and products without harming the environment or human health and production of nanoproducts that*

provides solutions to environmental problems: This involves application of existing principles of green chemistry and green engineering to produce nanomaterials without employing toxic ingredients, at comparatively low temperatures and using less energy and renewable inputs wherever and whenever possible and utilizing life cycle thoughts in all stages of design and engineering. In addition, this field also means using nanotechnology to make current manufacturing processes for non-nanomaterials and more eco-friendly products. For instance, nanoscale membranes can separate desired chemical reaction products from waste materials. More efficient and less wasteful chemical reactions are possible by employment of nanoscale catalysts. Nanoscale sensors can form part of process control systems, working with nano-enabled information systems. Using alternative systems via nanotechnology is another way to "green" manufacturing processes.

2. *Development of products that benefit the environment either directly or indirectly*: Nanomaterials have been found capable of directly cleaning hazardous waste sites, desalinate water and treat pollutants. Indirectly, lightweight nanocomposites for automobiles and other means of transport have been able to save fuel and reduce materials used for production. Nanotechnology-enabled fuel cells and LEDs are capable of reducing energy from energy generation and aid in fossil fuel conservation. Self-cleaning nanoscale surfaces have the ability to reduce or eliminate many cleaning chemicals used in regular maintenance routines (Sustainable Nano Coatings 2013). Green nanotechnology has a wider view of nanomaterials and nanoproducts, ensuring minimization of unforeseen consequences and anticipation of the impacts throughout the life cycle (Klöppfer et al. 2007).

Current research involves the development of nanotechnology in solar cells which are a renewable resource (Gail 2009). The potentials of this field are already in application for provision of improved performance coatings for photovoltaic (PV) and solar thermal panels. Hydrophobic and self-cleaning properties combine to create more efficient solar panels. PV panels covered with nanotechnology coatings have found to stay cleaner for longer duration thus ensuring maintenance of maximum energy efficiency (nanoShell 2013).

3 Green Chemistry

Green chemistry, also called sustainable chemistry, is a philosophy of chemical research and engineering that encourages the design of products and processes that minimize the use and generation of hazardous substances. It differs from environmental chemistry in the fact that environmental chemistry deals with chemistry of the natural environment and of pollutant chemicals in nature. Whereas in green chemistry it seeks answers to questions regarding reduction and prevention of pollution at its source, which in turn applies to organic chemistry, inorganic chemistry, biochemistry, analytical chemistry, and physical chemistry (USEPA 2006). Three key developments have been identified in green chemistry (Noyori 2005):

1. Use of supercritical CO_2 as green solvent
2. Use of aqueous H_2O_2 for clean oxidations
3. Use of hydrogen in asymmetric synthesis

3.1 Principles of Green Chemistry

Green chemistry has 12 principles that explain what the definition means practically and covers the following concepts (Anastas and Warner 1998):

1. Design of processes to maximize the amount of raw materials that ends up as products.
2. Use of safe, environment-benign substances whenever possible.
3. Design of energy-efficient processes.
4. The best form of waste disposal: avoid creating it in the first place.

The 12 principles are as follows:

1. *Prevention*: Better to prevent waste than to treat or clean up waste after it has been created.

2. *Atom economy*: Designing of synthetic methods to maximize the incorporation of all materials used in the process into the final product.
3. *Less hazardous chemical syntheses*: Designing of synthetic methods, wherever practicable, to use and generate substances that possess little or no toxicity to human health and the environment.
4. *Designing safer chemicals*: Designing of chemical products to affect their desired function while minimizing their toxicity.
5. *Safer solvents and auxiliaries*: Use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. *Design for energy efficiency*: Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. *Use of renewable feedstocks*: A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. *Reduce derivatives*: Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible because such steps require additional reagents and can generate waste.
9. *Catalysis*: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. *Design for degradation*: Chemical products should be designed so that at the end of their function, they break down into innocuous degradation products and do not persist in the environment.
11. *Real-time analysis for pollution prevention*: Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. *Inherently safer chemistry for accident prevention*: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents including releases, explosions, and fires.

Green chemistry is being increasingly used as a powerful tool for evaluation of environmental impact of nanotechnology by researchers (Schmidt 2007).

4 Green Engineering

Green engineering is the process and design of products that conserve natural resources and impact the natural environment as little as possible. The term is mostly used in connection to housing, but is also applicable to automobiles, lights, or anything that requires engineering, with incorporation of environmental principles. Green engineers are specially trained in the field with regard to making of materials in an environmentally friendly way. For example, in case of housing, they are concerned with the latest building materials and techniques, which may include the use of solar-powered devices like water heaters, solar lights or windows, and other design elements. Concepts used in automobiles that are considered environmentally friendly include hybrid technologies such as flex-fuel vehicles and electricity. The consumption of less energy could mean a chance to realize cost savings in the operations of these vehicles over time (Ken 2013).

4.1 Principles of Green Engineering

Green engineering has the following 12 principles (Anastas and Zimmerman 2003):

1. *Inherent rather than circumstantial*: Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.
2. *Prevention instead of treatment*: Better to prevent waste than to treat after formation.
3. *Design for separation*: Designing of separation and purification operations to minimize energy consumption and material use.

4. *Maximize efficiency*: Designing of products, processes, and systems to maximize mass, energy, space, and time efficiency.
5. *Output pulled* versus *input pushed*: Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
6. *Conserve complexity*: Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. *Durability rather than immortality*: Design goal should target durability than immortality.
8. *Meet need, minimize excess*: Design for unnecessary capacity or capability should be considered a flawed design.
9. *Minimize material diversity*: For promotion of disassembly and value retention.
10. *Integrate material and energy flows*: Design of products, processes, and systems should include integration and interconnectivity with available energy and material flows.
11. *Design for commercial "after life"*: Designing of products, processes, and systems for performance in a commercial "after life."
12. *Renewable rather than depleting*: Material and energy inputs should be renewable rather than depleting.

5 Nanobiosynthesis

Nanobiosynthesis or biogenic production of nanoparticles refers to the use of several species of bacteria, plants, yeast, and fungi for production of nanoparticles or to aid in the process. "Green" synthesis particularly refers to use of plants for production of nanoparticles. Nanobiosynthesis is of great interest due to simplicity of procedures, versatility, and environmental friendliness. Besides, the biologically fabricated nanostructures offer substantially different properties such as good adhesion, tribologically good properties, and optical and electrical properties of high interest in optoelectronics (Popescu et al. 2010). The general biosynthesis of metal nanoparticles from biological sources is depicted in Fig. 1 (Li et al. 2007b; Sharma et al. 2009; Prathna et al. 2010).

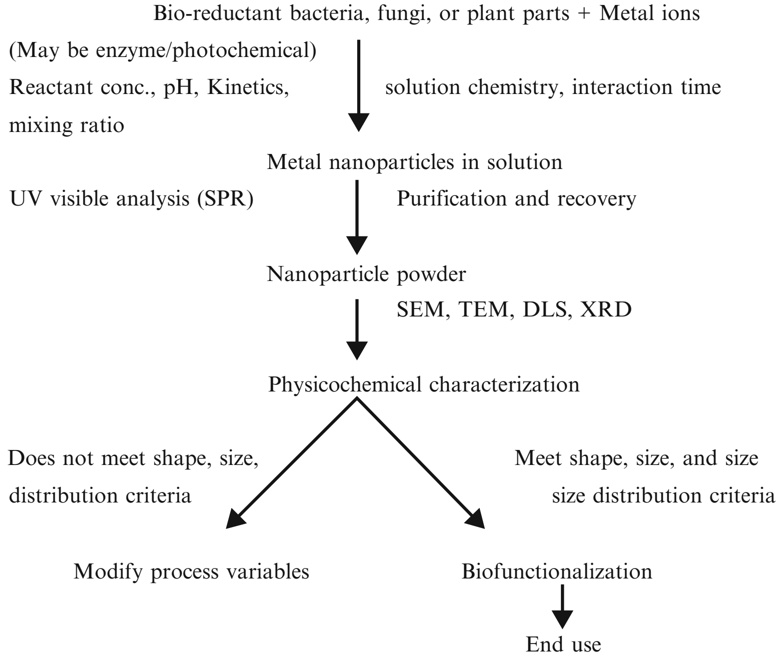

Fig. 1 Generalized flow chart for nanobiosynthesis (Prathna et al. 2010)

Nanoparticles that produced the "green" way include gold, silver, platinum, palladium, metal oxide, metal sulfide, nonmetal oxide, nanocomposites, magnetic, and alloy (Popescu et al. 2010; Song et al. 2010; Li et al. 2011; Sundrarajan and Gowri 2011; Hasna et al. 2012; Velayutham et al. 2012; Soundarrajan et al. 2012).

Microorganisms and plants have different mechanisms for nanobiosynthesis. Mechanism for nanoparticle formations varies for different microorganisms. However, they have a common path as metal ions are first trapped on the surface or inside of the microbial cells, which are then reduced to nanoparticles in the presence of enzymes. Generally, microorganisms impact mineral formation in the following two ways (Benzerara et al. 2011):

1. They modify the composition of the solution so that it becomes supersaturated or more supersaturated than it previously was with respect to a specific phase.
2. They impact mineral formation via production of organic polymers that are capable of having an impact on nucleation by favoring or inhibiting the stabilization of the very first mineral seeds.

Various mechanisms exist for nanoparticle formation by plants. Phytomining involves the use of hyperaccumulating plants to extract a metal from soil with recovery of the metal from biomass to return an economic profit (Lamb et al. 2001). Hyperaccumulator species have physiological mechanism that regulates the soil solution concentration of metals. Exudates of metal chelates from root system, for example, will allow increased flux of soluble metal complexes throughout the root membranes (Arya 2010). It has been observed that stress-tolerant plants have more capacity to reduce metal ions to the metal nanoparticles (Ankamwar et al. 2005a). Mechanism of nanobiosynthesis in plants may be associated with phytoremediation concept in plants (Huang and Cunningham 1996; Anderson et al. 1998; Haverkamp et al. 2007). Biosilicification also results in nanoparticles in cases of some higher plants as shown in Fig. 2 (Lopez et al. 2005).

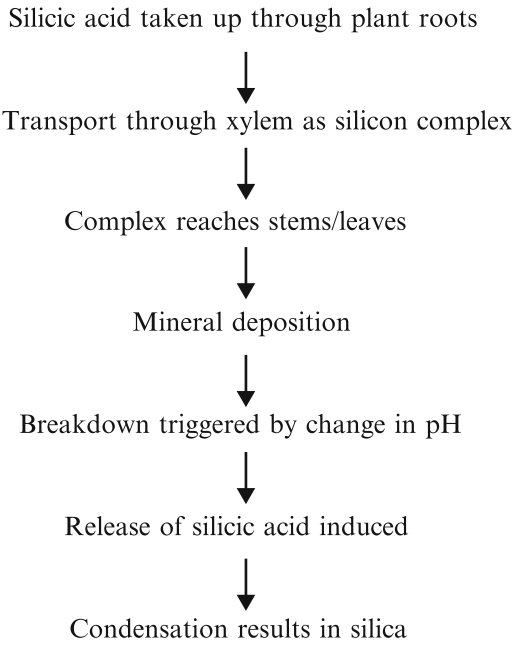

Fig. 2 Flow chart for biosilicification process

6 Role of Green Nanoparticles for Environmental Applications

Nanoparticles with antimicrobial potential like gold, silver, magnesium oxide, copper oxide, aluminum, titanium dioxide, and zinc oxide are widely used in water purification systems, in wastewater treatment, as self-cleaning and self-disinfecting agents, and as antimicrobial coatings in the wallpapers in hospitals (Ravishankar Rai and Jamuna Bai 2011). The categories of nanoparticles studied for environmental applications also include iron, bimetallics, catalytic particles, clays, carbon nanotubes, fullerenes, dendrimers, and magnetic nanoparticles (Mansoori et al. 2008).

6.1 Gold Nanoparticles

They have been precipitated within bacterial cells by incubation of cells with Au^{3+} ions (Beveridge and Murray 1980). Extracellular synthesis was reported in *Fusarium oxysporum* and *Thermomonospora* sp. and intracellular in

Verticillium sp. (Mukherjee et al. 2001, 2002; Ahmad et al. 2003a). Monodisperse particles have been synthesized using alkalotolerant *Rhodococcus* sp. under extreme biological conditions like alkaline and slightly elevated temperature conditions (Ahmad et al. 2003b). Aggregated forms of nanoparticles like gold nanotriangles have been reported in lemon grass extracts and tamarind leaf extracts (Ankamwar et al. 2005b). Extracellular synthesis of gold nanoparticles has also been observed using *Emblica officinalis* fruit extract as a reducing agent (Ankamwar et al. 2005a). Synthesis of gold nanostructures in different shapes (spherical, cubic, and octahedral) has been possible by the use of filamentous cyanobacteria from Au (I)-thiosulfate and Au (III)-chloride complexes (Lengke et al. 2006). Dead biomass of *Humulus lupulus* and leaf extract of *Ocimum basilicum* also produce gold nanoparticles (Lopez et al. 2005; Singhal et al. 2012). Gold nanoparticles are being developed for fuel cell applications which would be useful in automotive and display industry (Thompson 2007). Gold nanoparticles embedded in porous manganese oxide act as room temperature catalyst to break down volatile organic pollutants in air. Palladium-coated gold nanoparticles are very effective catalysts for removing trichloroethane (TCE) from groundwater 2,200 times better than palladium alone (Tiwari et al. 2008). The use of gold nanoparticles in colorimetric sensors enables identification of foods suitable for consumption. Other methods, such as surface-enhanced Raman spectroscopy, exploit gold nanoparticles as substrates to enable the measurement of vibrational energies of chemical bonds, which can be used for the detection of proteins, pollutants, and other label-free molecules (Ali et al. 2012).

6.2 Silver Nanoparticles

Pseudomonas stutzeri AG 259 isolated from silver mine formed silver nanoparticles when placed in silver nitrate solution (Klaus-Joerger et al. 2001). High quantity of silver nanoparticles is obtained using silver-tolerant yeast strains MKY3 (Kowshik et al. 2003). Silver nanoparticles have been reported from *Pleurotus sajor caju* along with its antimicrobial activity (Nithya and Raghunathan 2009). Extracellular biosynthesis of silver nanoparticles has been reported using marine cyanobacterium *Oscillatoria willei* NTDM01 that reduces silver ions and stabilizes the silver nanoparticles by a secreted protein (Ali et al. 2011). Silver nanoparticles have been produced in the form of a film or produced in solution or accumulated on cell surface of *Verticillium*, *Fusarium oxysporum*, or *Aspergillus flavus* (Senapati et al. 2004; Bhainsa and D'Souza 2006; Vigneshwaran et al. 2007; Jain et al. 2011). Silver nanoparticles with potential antimicrobial activity against *Escherichia coli*, *Vibrio cholerae*, *Salmonella typhimurium*, *Pseudomonas putida*, *P. vulgaris*, and *P. aeruginosa* have been reported from leaves of *Acalypha indica* and *Nicotiana tabacum*, peels of *Citrus sinensis*, and stem of *Allium cepa* (Krishnaraj et al. 2010; Saxena et al. 2010; Konwarh et al. 2011; Prasad et al. 2011). Silver nanoparticles produced with the aid of zeolite are a good sorbent for the removal of vapor-phase mercury from the flue gas of coal-fired power plants (Dong et al. 2009). They are effective antimicrobial compounds against coliform found in wastewater and incorporated as an antimicrobial, antibiotic, and antifungal agent in coatings, nanofiber, first-aid bandages, plastics, soaps, and textiles, in the treatment of certain viruses, in self-cleaning fabrics, as conductive filler, and in nanowire and certain catalyst applications (Jain and Pradeep 2005; Tiwari et al. 2008). The effect of loaded silver nanoparticles on TiO_2 has been studied for the degradation of Acid Red 88 (Anandan et al. 2008). Their presence has been found to significantly enhance DP25-TiO_2-mediated photodegradation of methyl orange at pH 6.6 (Gomathi Devi and Mohan Reddy 2010). The behavior of silver nanoparticles in a pilot wastewater treatment plant fed with municipal wastewater was investigated. TEM analyses confirmed the sorption of silver nanoparticles to wastewater biosolids, both in the sludge and effluent, and freely dispersed particles were observed only during the initial pulse spike in the effluent. XAS measurements indicated that most of the nanoparticles were present as Ag_2S in the sludge and effluent, which points to the potential of silver nanoparticles in wastewater treatment (Kaegi et al. 2011).

6.3 Palladium Nanoparticles

Palladium nanoparticles have been synthesized using coffee and tea extract at room temperature (Nadagouda and Varma 2008). Reports for its synthesis using broth of *Cinnamomum camphora* leaf are also available (Yang et al. 2010). Reaction of cyanobacterial biomass (*Plectonema boryanum* UTEX 485) with aqueous palladium (II) chloride at 250 °C for up to 28 days produced palladium nanoparticles (Lengke et al. 2007). Oleylamine-mediated synthesis of palladium nanoparticles was found useful for formic acid oxidation in $HClO_4$ solution. The catalyst showed no obvious activity degradation after 1,500 cyclic voltammetry cycles under ambient conditions, thereby holding promise as a highly active non-Pt catalyst for fuel cell applications (Mazumder and Sun 2009). Chemoselective hydrogenation of nitroarenes has been possible by the use of carbon nanofiber-supported palladium nanoparticles (Takasaki et al. 2008). Catalytically active membranes incorporated with microbially produced palladium nanoparticles have been employed for the removal of diatrizoate (Hennebel et al. 2010). Remediation of trichloroethylene has been possible by use of bioprecipitated and encapsulated palladium nanoparticles in a fixed bed reactor (Hennebel et al. 2009). Palladium nanoparticles electrodeposited on carbon ionic liquid composite electrode are useful for electrocatalytic oxidation of formaldehyde which is comparatively far superior to many of the previously reported formaldehyde sensors (Safavi et al. 2009). Photooxidation of xylenol orange is possible in the presence of palladium-modified TiO_2 catalysts, which is higher than the semiconducting support, being influenced by the size of the palladium clusters on the support (Iliev et al. 2004). Nitrogen/palladium-codoped TiO_2 enables photocatalytic degradation in 3 h for eosin yellow, which is carcinogenic and usually not easily treatable by conventional chemical or biological water treatment methods (Kuvarega et al. 2011). Palladium-modified nitrogen-doped titanium oxide showed enhanced photocatalytic degradation of humic acid over TiON within a narrow range of palladium concentration (Li et al. 2007a). Pd-modified WO_3 is an efficient tool for the decolorization of wastewater under solar light (Liu et al. 2010). New biological methods have been developed to recover precious metals from waste streams and to concomitantly produce palladium nanoparticles on bacteria, that is, bio-Pd, which serves as an effective catalyst for dehalogenation of environmental contaminants, hydrogenation, reduction, and CC reactions (Hennebel et al. 2012).

6.4 Metal Oxide Nanoparticles

Milky latex of *Calotropis procera* and *Aloe vera* extract has been used for the synthesis of “green” zinc oxide nanoparticles which are used in removal of arsenic from water (Tiwari et al. 2008; Sangeetha et al. 2011). It serves as potential UV absorbers for textiles and exhibits photocatalysis that finds application in wastewater treatment, degradation of dyes and other toxic compounds, and soil remediation (Becheri et al. 2008). Manganese-doped zinc oxide nanoparticles have been employed in the photocatalytic degradation of organic dyes (Ullah and Dutta 2008). Nanocrystalline MgO, CaO, TiO_2, and Al_2O_3 adsorb polar organics such as aldehydes and ketones in very high capacities and substantially out perform the activated carbon samples that are normally utilized for such purposes (Khaleel et al. 1999; Lucas and Klabunde 1999). Many years of research at Kansas State University, and later at Nano Scale, have clearly established the destructive adsorption capability of nanoparticles toward many hazardous substances including chlorocarbons, acid gases, common air pollutants, dimethyl methylphosphonate (DMMP), and paraoxon, 2-chloroethyl ethyl sulfide (2-CEES) and even military agents such as GD, VX, and HD (Wagner et al. 1999, 2000, 2001; Rajagopalan et al. 2002). Nanocrystalline metal oxides are particularly effective decontaminants for several classes of environmentally problematic compounds at elevated temperatures, enabling complete destruction of these compounds at considerably lower temperatures than that required for incineration (Decker et al. 2002). The application of nanocrystalline materials as destructive adsorbents for acid gases such as HCl, HBr, CO_2, H_2S, NO_X, and SO_X has been found to be more effective than commercially available oxides (Klabunde et al. 1996; Stark and Klabunde 1996; Carnes et al. 2002). In waste and wastewater treatment, MgO facilitates the adsorption and precipitation of silica and heavy metals and helps in preventing scale formation in boilers, heat exchangers, and piping. For soil remediation, it is an excellent pH modifier and heavy metal scavenger in contaminated soils and also effectively precipitates heavy metals, thus preventing subsequent leaching from treated soils (http://www.baymag.com). Copper oxide nanoparticles have been synthesized using gram-negative bacterium of the genus *Serratia* and *Aloe vera* extract (Saif Hasan et al. 2008; Sangeetha et al. 2012). Cupric oxide can safely dispose hazardous materials like cyanide, hydrocarbons, halogenated hydrocarbons, and dioxins through oxidation (Kenney and Uchida 2007). Copper oxide nanocrystals also possess photocatalytic, photovoltaic, and photoconductive functionalities (Kwak and Kim 2005). Titanium oxide has been synthesized via the "green" route using leaf extracts of *Catharanthus roseus* and *Nyctanthes arbor-tristis* and R5 peptide derived from diatom *Cylindrotheca fusiformis* and also using *Lactobacillus* sp. and Saccharomyces cerevisiae (Sewell and Wright 2006; Jha et al. 2009; Sundrarajan and Gowri 2011; Velayutham et al. 2012). It serves as photocatalyst in detoxification of wastewater (Jones et al. 2007). Semiconducting properties of TiO_2 materials are responsible for the removal of various organic pollutants (Makarova et al. 2000). Degradation of nitrobenzene has been achieved using nano-TiO_2 (Yang et al. 2007). The bacterium *Actinobacter* sp. has been shown to be capable of synthesizing iron-based nanoparticles under ambient conditions depending on the nature of precursors used (Bharde et al. 2005, 2008). They are being used to clean carbon tetrachloride in groundwater and arsenic from water wells. The use of zerovalent iron (ZVI or Fe^0) for in situ remedial treatment has been expanded to include all different kinds of contaminants (Ponder et al. 2000).

6.5 Platinum Nanoparticles

They have been synthesized using >10 % *Diospyros kaki* leaf extract as reducing agent from an aqueous $H_2PtCl_6.6H_2O$ solution at a reaction temperature of 95 °C and as reducing agent from aqueous chloroplatinic acid at a reaction temperature of 100 °C that finds application in water electrolysis (Song et al. 2010; Soundarrajan et al. 2012). Preferential oxidation of carbon monoxide is important for purification of H_2 for use in polymer electrolyte fuel cells which has been possible with platinum nanoparticles in mesoporous silica with unprecedented activity, selectivity, and durability below 353 K (Fukuoka et al. 2007).

7 Barriers and Challenges to Commercialization of Green Nanotechnology (ACS 2011)

1. Lack of clear design guidelines for researchers in initial discovery phases of green nanoscience. The choices made for the synthesis of new green nanomaterials can affect throughout the development and commercialization process which most researchers are unaware of.
2. Many green nanomaterials require new commercial production techniques, which increases the need for basic research, engineering research, and coordination of the two between the industrial and research communities, as the challenges do not appear until firms begin to produce in large quantities. This problem is common for small companies and start-ups and solutions rely at least partially on work done by the research community.

3. Lack of a "deep bench" of scientists and engineers with experience in developing green nanotechnology. The impact of this situation is mostly apparent in small and large industrial firms.
4. Need for constant development and updating of toxicology and analysis protocols to reflect advances in science. There is also a need to develop in-line process analytical and control techniques for full-scale manufacturing operations by involvement from academic researchers.
5. Regulatory uncertainty persists, and green nanotechnologies often face higher regulatory barriers than existing or conventional chemicals. This affects small and large industrial firms as they attempt to move green nanotechnologies into the market.
6. The end-market demand is unclear, especially since there are only a limited number of commercial grade products that can be compared to conventional materials in terms of performance.

8 Actions to Be Taken to Overcome the Barriers (ACS 2011)

1. Discover, uncover, and provide key analysis and characterization tools. Reduce analysis costs.
2. Develop, characterize, and test precision-engineered nanoparticles for biological and toxicological studies needed to guide greener design. Develop reference libraries that provide the relevant data required and provide them to groups that need them for testing and also hypotheses that help in redesign of materials that are greener.
3. Investigate and understand reaction mechanisms to support more efficient and precise synthesis and production techniques. Screen for barriers and develop design guidelines for commercially producible green nanomaterials.
4. Develop design guidelines for green nanomaterials for early stage researchers and material developers to support greener nanomaterial development and production.
5. Definition of green criteria for new nanomaterials for fast-track approval by the US Environmental Protection Agency that demonstrates benefits over existing materials in market and possesses no hazard.
6. Education and outreach to regulators to ensure regulatory structures for green nanotechnology reflect accurate knowledge of their intended users and potential impacts.

9 Conclusion

Green nanotechnology is indeed an eco-friendly alternative for production of nanotechnology products for sustainable development of environment by provision of solutions to tackle the ever-expanding environmental issues like environmental degradation, depletion of natural resources, water and air pollution, and aftermaths of various other kinds of pollutions. The barriers need to be overcome by the right actions. This will be possible only by constant cooperation with a team comprising experts from multiple disciplines or rather various areas including science, commerce, and statistics that come up with solutions covering wide areas and problems that need to be addressed. If the suggestions that come up from such a discussion are rightly followed and literally put into practical action, then this potential field is sure to come up as the answer to all major environmental issues and thereby the future of tomorrow in a sustainable way.

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