Green and Eco-friendly Nanotechnology – Concepts and Industrial Prospects

Shubhrajyotsna Aithal[1*] & P. S. Aithal[2]
[1]Dept. of Chemistry, College of Engineering & Technology, Srinivas University, Mangalore, India
OrcidID: 0000-0003-1081-5820; E-mail: shubhraaithal@gmail.com
[2]College of Management & Commerce, Srinivas University, Mangalore – 575 001, INDIA
OrcidID: 0000-0002-4691-8736; E-mail: psaithal@gmail.com

Area/Section: Nanotechnology.
Type of the Paper: Research Analysis.
Type of Review: Peer Reviewed as per |C|O|P|E| guidance.
Indexed in: OpenAIRE.
DOI: http://doi.org/10.5281/zenodo.4496913
Google Scholar Citation: IJMTS.

How to Cite this Paper:

Aithal, Shubhrajyotsna & Aithal, P.S., (2020). Green and Eco-friendly Nanotechnology – Concepts and Industrial Prospects. *International Journal of Management, Technology, and Social Sciences (IJMTS), 6*(1), 1-31. DOI: http://doi.org/10.5281/zenodo.4496913.

International Journal of Management, Technology, and Social Sciences (IJMTS)
A Refereed International Journal of Srinivas University, India.

CrossRef DOI: https://doi.org/10.47992/IJMTS.2581.6012.0127

Green and Eco-friendly Nanotechnology – Concepts and Industrial Prospects

Shubhrajyotsna Aithal[1*] & P. S. Aithal[2]
[1]Dept. of Chemistry, College of Engineering & Technology, Srinivas University, Mangalore, India
OrcidID: 0000-0003-1081-5820; E-mail: shubhraaithal@gmail.com
[2]College of Management & Commerce, Srinivas University, Mangalore – 575 001, INDIA
OrcidID: 0000-0002-4691-8736; E-mail: psaithal@gmail.com

ABSTRACT

Nanotechnology is considered as a tool for solving problems and providing comfort in the livelihood of human beings, also possess challenges and treats if not used carefully. nanotechnology if used properly can support to realize the 17 Sustainable Development Goals (SDG) to be realized by 2030. Nanotechnology, being multidisciplinary frontier technology useful for innovative solutions in primary, secondary, tertiary, and quaternary industry sectors has shown slow progress due to its potential risks due to predicted nanotoxicity. To counter this but to use nanotechnology solutions in societal progress, green and eco-friendly nanotechnology solutions play a major role in realizing sustainable development goals and eliminates the threat of the technification of development processes. This paper discusses the concept, current research outcome, and the industrial prospects of achieving global SDG and much more using green and eco-friendly nanotechnology in 21st century.

Keywords: Nanotechnology (NT), Green nanotechnology (GNT), Green nanomaterials, Industrial prospects, Primary industry sector, Secondary industry sector, Tertiary industry sector, Quaternary industry sector, Green synthesis, Eco-friendly production, Technification, ICCT

1. INTRODUCTION :

Identifying problems as challenges and involving in solving them is the nature of innovators in society. In this process, the technology is used as a tool. Most of the current problems of human beings related to basic needs, advanced wants, and dreamy desires can be solved using 21st century technologies, which include nanotechnology (NT) and information communication technology (ICCT) [1]. Though the word nanotechnology is first used by a Japanese Professor Norio Taniguchi of Tokyo University of Science in 1974 conference to describe the characteristics of a thin film of the order of a nanometer, the idea is originally proposed by Richard Feynman in 1959 in his speech on There's plenty of space at the bottom at the American Physical Society meeting. Thereafter in 1981, Eric Drexler independently used the word nanotechnology in his scholarly publication. The discovery of scanning tunnelling microscope in 1980 and the invention of fullerenes in 1985, supported for the initial development of nanotechnology. In 1986, Eric Drexler published a book on Engine of Creation and Nanosystems, which proposed the idea of nanoscale devices using nanotechnology. Further development of semiconductor nanocrystals, metal oxide nanoparticles, nano-quantum dots, and the invention of the atomic force microscope further fuelled the growth of nanotechnology as a general-purpose technology [2]. After that nanotechnology became research topics of all areas of basic sciences and applied sciences due to its potential ability and advantages of solving scientific, engineering, and industrial problems [3]. At the beginning of the 21st century, the developments in nanotechnology are accelerated due to its wide acceptance as frontier technology development area, and many postgraduate and research programmes were started through country governments intensified research funding.

Even though nanotechnology involves manipulating matter on an atomic, molecular, and supramolecular scale, the particular technological goal is of precisely manipulating atoms and

molecules for the fabrication of macroscale products, also now referred to as molecular nanotechnology. Nanotechnology being a general-purpose technology encompassing four generations of products with increasing structural and dynamic complexity as (1) passive nanostructure (2) active nanostructures, (3) nanosystems, and (4) molecular nanosystems. It is predicted that by 2020, the increasing integration of nanoscale science and engineering knowledge and of nanosystems promises mass applications of nanotechnology in industry, medicine, and computing and in better comprehension and conservation of nature. Nanotechnology's rapid development worldwide is supporting this anticipation of its expected progress of transforming the society and the future of living beings. However, the slow pace of actual progress against predicted roadmap has been re-examined and based on more planned efforts to be made by country governments and nanotechnology research organizations the modified timeline of nanotechnology industry progress is predicted by Aithal et al. (2015) [4-5], based on the last 15 years development trend and listed in Table 1. The delay is mainly due to the fear and caution of many scientists, organizations, and country governments on fast acceptance for the nanotechnology commercialization process. However, through currently developed and proven green and eco-friendly nanotechnology processes further accelerates the nonotechnology growth and to stick the timeline as per predicted in Table 1.

Table 1: Anticipated Timeline of Nanotechnology Innovations [5]

Nanotech Generations	Development	Examples	Prediction by Roco 2004 [6]	Prediction by Aithal et al. (2015) [5]
First Generation	**Passive Nanostructures** Ex : Coatings, nanoparticles, nanostructured metals, polymers, ceramics.	Nanomaterials, including nanotubes and nanolayers.	2000 - 2005	2000 - 2015
Second Generation	**Active Nanostructures** Ex : 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures.	Change their state during use, responding in predictable ways to the environment.	2006 - 2010	2016 – 2020
Third Generation	**Nanosystems** Ex : Guided assembling; 3D networking and new hierarchical architectures, robotics.	Assemblies of nanotools work together to achieve a final goal.	2011 – 2015	2021 – 2035
Fourth Generation	**Molecular Nanosystems** Ex : Molecular devices 'by design', atomic design, Gene therapy.	Involves the intelligent design of molecular and atomic devices, leading to "unprecedented understanding and control over the basic building blocks of all natural and man-made things.	2016 - 2020	2036 - 2050
Fifth Generation	**Singularity**	Growth rate in NT applications becomes infinite.	2020 - 2025	Beyond 2050

As per the table1, nanotechnology is in the transition from its second generation to the third generation. The active nanostructures like 3D transistors, amplifiers, targeted drugs, actuators, adaptive structures using metal-nanomaterials, metal-nanocomposites, semiconductor nanocomposites, and nano-quantum dots are achieved and the next generation of nanosystems to fabricate Guided assembling systems, 3D networking systems, and new hierarchical architecture systems and robotics using nanosystems are approaching from coming years. The developed nanosystems for the next industrial revolution called industry 5.0 with the objective of total automation and mass customization can be achieved only if the fear of adopting nanotechnology systems in industries. By means of developing and promoting green and eco-friendly nanosystems [7-8] the technology can spread at an accelerated speed and many more components, devices and systems will be commercialized from different industries. Nanotechnology can become a part of ideal technology that can solve all problems of society optimally, provided the potential risks are taken care of.

In this paper, we have analysed the industrial prospective and risks of nanotechnology and suggested how to use green nanotechnology models to solve the potential risks and hence add values to products and processes of basic needs, advanced wants, and dreamy desires in Primary industry sector including agriculture, drinking water, and forestry, Secondary industry sector including food processing, renewable energy, construction & manufacturing of various consumable products, Tertiary industrial sector including Transportation & tourism, entertainment, financial services, and health services, and Quaternary industry sector including information communication and computation technology (ICCT).

2. RELATED RESEARCH WORKS :

Green nanotechnology deals with environmentally friendly processes of preparation, large-scale manufacturing, and industrial use of nanomaterials by minimizing environmental degradation and potential risks of health hazards. A systematic review of important related works published recently on various underlying areas of green nanotechnology is listed in table 2 by identifying issues of environmental degradation. Based on the review and current understanding of various issues of environmental degradation, the opportunities and challenges of using nanotechnology as green and eco-friendly technology is discussed and analysed.

Table 2 : Review on research scholarly publications in green nanotechnology related areas

S. No.	Area	Issue & Outcome	Reference
1	Environmental Challenges of Production of Nanomaterials	Challenges in Toxicity and environmental risks of nanomaterials	Ray, P. C. et al. (2009). [9]
		Risks of nanomaterials in aquatic and terrestrial environments	Batley, G. E. et al. (2013). [10]
		Environmental risk assessment of nano-TiO2, nano-Ag, nano-ZnO, CNT, and fullerenes	Coll, C. et. al. (2016). [11]
		Potential health risks of nanomaterials used in Biomedical applications	Lanone, S. et al. (2006). [12]
		Risks of nanomaterials used in regenerative medicine, delivery systems, theragnostic, and therapy.	Medina-Reyes, E. I. et al. (2017). [13]
		Frameworks and tools for risk assessment of manufactured nanomaterials	Hristozov, D., et al. (2016). [14]

2	Green Production of Nanomaterials	Green production of carbon nanomaterials	Rezaei, A. et al. (2018). [15]
		Green nanotechnology of Au particles from plant extracts	Geraldes, A. N. et al. (2016). [16]
		Green Manufacturing of Ultrapure Engineered Nanomaterials	Ortiz de Zárate, D. et al. (2020). [17]
		Green synthesis of iron nanoparticles	Saif, S. et al. (2016). [19]
		Green approach for the production of zinc oxide nanoparticles	Al-Dhabi, N. A. et al. (2018). [19]
		Eco-friendly approaches for green synthesis of silver nanoparticles	Bhosale, R. R. et al. (2014). [20]
3	Nanomaterials for Agriculture & Food industries	Role of nanotechnology in agriculture with special reference to the management of insect pests	Rai, M. et al. (2012). [21]
		Novel environment-friendly crop improvement strategies	Yashveer, S. et al. (2014). [22]
		Nanomaterials in food and agriculture: safety concerns and regulatory issues	Jain, A. et al. (2018). [23]
		Nanosensors applications in agriculture and food industry	Omanović-Mikličanina, E. et al. (2016). [24]
		Nanomaterials in plant protection	Mazzaglia, A. et al. (2017). [25]
		Nanomaterials for food packaging	Huang, Y. et al. (2018). [26]
		Nanotechnology in precision agriculture	Duhan, J. S. et al. (2017). [27]
4	Nanomaterials for potable water and Clean Environment Industry	Ideal Water Purifier System using nanotechnology	Aithal, P. S. et al. (2018). [28]
		Nanotechnology for water treatment – a green approach	Patanjali, P. et al. (2019). [29]
		Synthesis and applications of biogenic nanomaterials in drinking and wastewater treatment	Gautam, P. K. et al. (2019). [30]

		Remediation of water and wastewater by using engineered nanomaterials	Bishoge, O. K. et al. (2018). [31]
		Nanotechnology applicability in industrial wastewater treatment	Kamali, M. et al. (2019). [32]
		New generation nanomaterials for water desalination	Teow, Y. H. et al. (2019). [33]
		Engineered nanomaterials for water treatment and remediation	Adeleye, A. S. et al. (2016). [34]
		Sustainable Development of Environment using Green nanomaterials	Sivaraj, R. et al. (2016). [35]
5	Nanomaterials for Renewable Energy	Nanotechnology Innovations & Business Opportunities in Renewable Energy Sector	Aithal P.S. et al. (2016). [36]
		Concept & Characteristics of Ideal Energy System	Aithal, P. S. et al. (2018). [37]
		Realization Opportunity of Ideal Energy System using Nanotechnology	Shubhrajyotsna Aithal et al. (2018). [38]
		Nanomaterial used in clean energy technologies	Moore, E. A. et al. (2018). [39]
		Green nanotechnology of trends in future energy	Guo, K. W. (2012). [40]
		Nanotechnology for achieving green-economy through sustainable energy	Pandey, G. (2018). [41]
		Nanomaterials for energy conversion and storage	Choi, J. W. et al. (2016). [42]
		Polydopamine-inspired nanomaterials for energy conversion and storage	Qu, K., (2018). [43]
6	Nanomaterials for Infrastructure & Construction	Nanomaterials in cementitious composites	Adesina, A. (2020). [44]
		Reinforcement efficiency of low-cost graphite nanomaterials in high-performance concrete	Peyvandi, A. et al. (2018). [45]
		Nanomaterials to enhance microstructure and mechanical properties of concrete	Kwalramani, M. A. et al. (2018). [46]

		Nanotechnology as a preventive engineering solution to highway infrastructure failures	Ugwu, O. O. et al. (2013). [47]
		Nanotechnology innovations for the sustainable buildings of the future	Sev, A. et al. (2014). [48]
		Energy savings and sustainable construction	Oke, A. E. et al. (2017). [49]
7	Nanomaterials for Cosmetics	Use of nanomaterials in cosmetics	Yapar, E. A. et al. (2012). [50]
		Current role of nanomaterials in cosmetics	Srinivas, K. (2016). [51]
		Present situation and future of nanomaterials in cosmetics	Masunaga, T. (2014). [52]
		Gold nanomaterials in consumer cosmetics nanoproducts	Cao, M. et al. (2016). [53]
		Role of Nanostructured Materials in Cosmetics	Bilal, M. et al. (2020). [54]
		Silver nanoparticles in cosmetics	Gajbhiye, S. et al. (2016). [55]
		Material Engineering and Nanotechnology for Improving Sports Performance and Equipment	Shalaby, M. N. et al. (2020). [56]
8	Nanomaterials for Transportation & Automobiles	Potential applications of nanotechnology in transportation	Mathew, J. et al. (2019) [57]
		Economic and environmental implications of using nanocomposites in automobiles	Lloyd, S. M. et al. (2003). [58]
		Nanotechnological Innovations & Business Environment for Indian Automobile Sector	Aithal, P. S. et al (2016). [59]
		Nanotechnology applications in future automobiles	Wallner, E. et al. (2010). [60]
		Nanotechnology in Automobile Industry for Efficiency Enhancement	Gurjar, B. S. et al. (2015). [61]
		Nanotechnology in transportation vehicles: an overview	Shafique, M. et al. (2019). [62]

		Applications of Carbon Nanotubes in Automobiles	Krishnan, A. et al. (2020). [63]
9	Nanomaterials for Consumer applications Industry	Nanomaterials in consumer products: a challenging analytical problem.	Contado, C. (2015). [64]
		Nanomaterials in consumer products	Hansen, S. F. et al. (2009). [65]
		Nanotechnology in the real world: Redeveloping the nanomaterial consumer products inventory	Vance, M. E. et al. (2015). [66]
10	Nanomaterials for Electronics & Computer Industry	MEMS and nanotechnology research for the electronics industry.	Pak, Y. E. (2001). [67]
		Inorganic nanomaterials for printed electronics	Wu, W. (2017). [68]
		Application of Carbon Nanotubes (CNT) on The Computer Science and Electrical Engineering	Moghaddam, H. K. et al. (2020). [69]
		Polymer nanocomposites and their applications in electronics industry	Tyagi, M. et al. (2014). [70]
		The Impact of Carbon Nanotubes and Graphene on Electronics Industry	Vargas-Bernal, R. et al. (2019). [71]
		Potential Impact of Nanomaterials in Information and Communication Technologies	Anuhya, K. H. et al. (2016). [73]
		Graphene-reinforced Polymeric Nanocomposites in Computer and Electronics industries	Kardanmoghaddam, H. et al. (2020). [73]
		Fully integrated graphene and carbon nanotube interconnects for gigahertz high-speed CMOS electronics	Chen, X. et al. (2010). [74]
		Carbon nanomaterials for non-volatile memories	Ahn, E. C. et al. (2018). [75]

		3D Assembly of Graphene Nanomaterials for Advanced Electronics	Le Ferrand, H. et al. (2020). [76]
11	Nanomaterials for Health & Pharmaceutical Industry	Impact of nanomaterials on health and environment	Thomas, S. P. et al. (2013). [77]
		Nanotherapeutics—product development along the "nanomaterial" discussion	Wacker, M. G. (2014). [78]
		Occupational safety and health criteria for responsible development of nanotechnology	Schulte, P. A. et al. (2014). [79]
		Effective drug delivery system of biopolymers based on nanomaterials and hydrogels	Gopi, S. et al. (2016). [80]
		Biopharmaceutics and therapeutic potential of engineered nanomaterials	Liang, X. J. et al. (2008). [81]
12	Nanomaterials for Space Industry	Engineered nanomaterials in aerospace	Arepalli, S. et al. (2015). [82]
		Carbon Nanomaterials on a Space Station Board	Rizakhanov, R. N. et al. (2012). [83]
		Nanotechnology safety in the aerospace industry	Haynes, H. et al. (2013). [84]
		Space electric propulsion systems based on smart nanomaterials	Levchenko, I. et al. (2018). [85]
		Bio-inspired hierarchical nanomaterials for space applications	Carpinteri, A. et al. (2008). [86]
		Potential space applications of nanomaterials	Novikov, L. S. et al. (2017). [87]

3. RESEARCH OBJECTIVES & METHODOLOGY :

To understand the possibility of using emerging nanotechnology as green and eco-friendly technology by means of the following objectives :

(1) To identify green processes for nanomaterial preparation, handling, and conversion into nanosystems.

(2) To discuss the current status and prospects of green nanotechnology in the Primary industry sector including agriculture, forestry, mining, fisheries, etc.

(3) To discuss the prospects of green nanotechnology in Secondary industry sector including (a) Potable water sector, (b) Environment Cleaning sector, (c) Food & Food Processing sector, (d) Renewable Energy sector, (e) Construction industry sector, (f) Consumable goods industry sector, (g) Automobiles industry, (h) Medical equipment's & Drug synthesis, etc.

(4) To discuss the prospects of green nanotechnology in Service industry sector including (a) Transportation & Space industry, (b) Telecommunication industry, (c) entertainment industry (d) Education & Research, (e) electronic & Photonics industry, (f) Healthcare industry, etc.
(5) To analyse the green and eco-friendly nanotechnology to realize the 17 SDG of the United Nations.

The current status of nanotechnology research in different industry sectors is studied through a systematic literature review and the nanomaterial prepared using green and eco-friendly methods and applications in some of the prominent industry sectors along with challenges and opportunities of green nanotechnology are also discussed. This technology analysis methodology is used to analyze the possibility of realization of the Sustainable Development Goal of the United Nations.

4. NANOTECHNOLOGY AND GLOBAL SUSTAINABLE DEVELOPMENT GOALS :

Nanotechnology (NT) and Information Communication and Computation technologies (ICCT) are combinedly called 21st century technologies and are potential realize the Sustainable Development Goals of United Nations Member States announced in 2015 with a slogan of action to end poverty, to protect the planet, and to ensure peace and prosperity by the year 2030. Table 3 lists the SD goals and suitable 21st technologies to achieve them to balance social, economic, and environmental sustainability. To realize each SD goal based on the objective of an issue as maximum or minimum, suitable technologies are selected and proposed. It is argued that nanotechnology and ICCT, individually or combinedly are capable to achieve global sustainable goals to a larger extent within the given target of 15 years [88].

Table 3 : SD goals and suitable technologies to achieve them

Goal No.	Focus Issue	Goal by 2030	Objective	Technology
1	Reduce Poverty	To Zero	Minimize	NT
2	Reduce Hunger	To Zero	Minimize	NT
3	Health & Well-Being	To Everyone	Maximize	NT
4	Quality Higher Education	To Everyone	Maximize	ICCT
5	Gender Equality	To Everyone	Maximize	ICCT
6	Clean Water & Sanitation	To Everyone	Maximize	NT
7	Affordable renewable energy	To Everyone	Maximize	NT
8	Decent Employment	To Everyone	Maximize	NT & ICCT
9	Sustainable Industrialization	Everywhere	Maximize	NT & ICCT
10	Reduced Inequalities among Countries	To Zero	Minimize	-
11	Safe & Sustainable Cities & Communities	Everywhere	Maximize	ICCT
12	Ensure sustainable Production & Consumption	Everywhere	Maximize	NT & ICCT

13	Combat on Climate Change	To Zero	Minimize	NT
14	Conserve Ocean & Marine Resources	Everywhere	Maximize	NT
15	Protect life on Land	Everywhere	Maximize	NT
16	Ensure Peace and Justice	To Everyone	Maximize	ICCT
17	Global Partnership for Sustainability	To Highest	Maximize	ICCT

5. IDEAL TECHNOLOGY - CONCEPT AND CHARACTERISTICS :

Technology is a tool to solve many problems in society. The concept of ideal technology is a hypothetical technology that can solve all problems of human beings and provide luxury and comfort in life without affecting the society and environment. Ideal technology should have characteristics in order to elevate the quality of life to a unique level with perfect equality so that every human being in this universe should lead a happy and comfortable life and realize the so-called concept of heaven on earth. Based on various factors which decide the ideal technology system characteristics, a model consisting of input conditions, output conditions, environmental conditions, and system requirements is developed [89]. The input properties are (1) Manipulate the fundamental nature of matter to provide solutions to the basic and advanced problems of mankind. (2) In-expensive & self-reliable in terms of resources to make it attractive to be used by people/countries of varied economical situations. (3) Ubiquitous so that the technology provides solutions and services at anytime, anywhere, any amount of time to the users. (4) Affordable to everybody so that it uses common materials available in nature and manipulate effectively to the need of a human being at an affordable cost. The output properties are (1) Solve basic needs like food, drinking water, renewable energy, clothing, shelter, health, and a clean environment. (2) Provide comfort life to the users by providing solutions to their desires. (3) Equality: ideal technology provides equal opportunity and similar solutions to every user irrespective of their gender, religion, background, education, economic status, and country of origin. (4) Automation; ideal technology automates all processes in every type of industry to avoid human interference in work/control in order to provide an expected output based on programming. (5) Immortality is the ultimate goal of ideal technology so that it can create an avenue for a deathless situation or enhancement of the human life span. The System Requirement Properties are (1) General purpose technology to support all fields and problems of human & living beings on the earth. (2) Self-directed & self-controlled & self-regulated so that technology can control itself in order to achieve its goal. (3) Easy, simple, quick & user friendly to solve all types of problems and to provide a quick ideal solution. (4) Scalable so that it is used for solving small and simple problems to large and complex problems of life. (5) Omni-potent to identify and solve problems and provide comfortability to human beings and feeling him like God. (6) Exploring new opportunities to improve and explore comfortability and further leisure in the life of people. (7) Infinite potential for further development of life in the universe. The Environment/external Properties are (1) Maintain a clean environment through its processes and avoid the footprint of processes, while achieving specific functions. (2) Infinite business opportunities by creating new products/services with ideal characteristics. (3) Adaptive to any situation to achieve the stated goal. (4) No side effects such that it should be safe for users, and the environment. Any technology which has the above properties/characteristics is considered as ideal technology and conventional technologies have serious drawbacks/limitations in terms of the above properties [89]. One of the properties of ideal technology is sustainability and zero green gas emissions to the environment i.e., ideal technology is green technology. Every technology can be made sustainable by adding green components so that they can avoid environmental degradation and converted into green technologies to provide a clean environment for future generations.

As discussed earlier, nanotechnology is expected to solve both the basic needs and comfort want of human beings. The basic needs of human beings are food, drinking water, energy, cloth, shelter, health and environment and the comfort wants are realizing automation in every field, space travel, and expanded lifespan, and so on. Nanotechnology is the manipulation of matter on an atomic, molecular, and supramolecular scale. Planned and controlled development of nanotechnology lead to environmental sustainability and hence can be used as green technology. Green nanotechnology is evolving as a general-purpose technology due to its applications in all areas of society. Hence in the advanced form, it will have a significant impact on almost all industries and all areas of society by offering better built, longer-lasting, cleaner, safer, and smarter products for the home, for communications, for medicine, for transportation, for agriculture, and for every industry, in general. Thus, by controlled utilization of nanotechnology for environmental sustainability, it can be developed as green nanotechnology technology for sustainable development.

6. USE OF UNIVERSAL TECHNOLOGIES TO REALIZE SUSTAINABLE DEVELOPMENTAL GOALS :

The dream of realizing Global sustainable development goals of the United Nations is possible through the proper use of technologies. In this process, two mega technologies, nanotechnology (NT) and Information Communication and Computation Technology (ICCT) have potential abilities and if used systematically by every participating country can reach the goal.

Nanotechnology being a mega technology with many branches including Nanomaterials Development Technology, Nanomechanics technology, Nanoelectronics Technology, Nanophotonics Technology, Nanobiotechnology, and Nanomedicine, is considered as a general-purpose technology of the 21st century. Nanotechnology has expected to change the rules of development games in many areas including Agriculture & Food industry, drinking water systems, Efficient Automobiles, Renewable energy systems, High speed optical computers, Low-cost durable shelters, Embedded intelligence, Space vehicles, Health & Medical solutions, etc.

Similarly, ICCT being a mega technology supports many innovative general-purpose technologies which are going to change the business models of almost every industry. ICCT underlying technologies are supporting total automation of primary, secondary, tertiary, and quaternary industries by creating artificial intelligence to replace human beings totally, ubiquitous 3D printing through IoT and Cloud computing, Optimum business model creation through data science and business analytics, online education, retailing, entertainment, social connections through virtual and augmented reality, and high speed processing of information supports the total transformation of society by changing the lifestyle and comfortability levels of individuals. ICCT allows human beings to become ubiquitous and total automated products and services for individuals and hence acts as a pillar of social, technological, and economical transformation.

These two technologies are capable to transform human life by offering more and more comfortability. As discussed earlier, every human being (1) needs nutritious food, clean drinking water, clean air, affordable shelter, energy from renewable sources, and good health as basic needs, (2) many products & services as advanced wants for comfortability and satisfaction, (3) Dreams to realize many individual and collective desires to enjoy and get happiness to acquire the status of super-human with three desired abilities as (a) Ubiquitous, (b) Omnipotent, and (c) immortal. Both Nanotechnology and ICCT can work together to realize the basic needs, advanced wants, dreamy desires at an affordable cost in the near future [90]. Since, based on our prediction of the ability of these two technologies to convert humans into super-humans in the process of transforming society by serving and solving everyone's problems, they are collectively called Universal technology [91]. This integration of ICCT and Nanotechnology into Universal technology allows us to solve all the above three kinds of problems in society.

7. RISKS ASSOCIATED WITH NANOTECHNOLOGY :

Though nanotechnology has innumerable benefits including improved manufacturing methods, improved environment and water purification systems, efficient renewable energy systems, physical systems property improvement and performance enhancement, optimization of health problems through

nanomedicine, better food production methods & enhanced nutrition in food, large-scale infrastructure auto-fabrication through self-replicating machines, etc, if not handled properly with creating proper awareness and precautions may have potential disadvantages in terms of risks to the health of living beings, environment, social life, and economy of the countries. Some of the issues related to health, environment, social, economic, and a newly predicted effect called green goo are discussed below:

(1) Health Related Risks :

Nanomaterials are expected to show toxicity effects that are not associated with larger particles. For example, even inert elements like gold become highly active at the nanometer dimensions. Size is a key factor in determining the potential toxicity of a particle. However, it is not the only important factor. Other properties of nanomaterials that influence toxicity include chemical composition, shape, surface structure, surface charge, aggregation and solubility, and the presence or absence of functional groups of other chemicals. The inhaling of nanoparticles due to their size may mainly cause the toxic effect of damage to the lungs and sometimes they may reach to the bloodstream and are predicted to cause heart problems. The ingestion of nanoparticles to the human body may also become toxic and lead to various diseases including colon cancer, Crohn's disease, arrhythmia, asthma, lung cancer, autoimmune diseases, neurological disease, etc. Only little is known about ill-effects of nanoparticles on the living body and further study, as well as precautions, are essential.

(2) Environmental Related Risks :

The unused nanoparticles or waste nanomaterials during synthesis may agglomerate into larger particles or longer chain with modified physical and chemical properties, which may expose to the environment and may enter to the human body and spread toxicity. Unused silver nanoparticles if mishandled may contaminate sewage sludge and affect the microorganisms of soil of agricultural fields. The silver nanoparticles show a toxic effect on fishes and other marine animals in the ocean. Silver nanoparticles at high concentrations may be toxic at high concentrations. Thus, it is assumed that nanotechnological products, processes, solutions, and different applications may affect significantly to the environment and climate. Thus, nanoparticles are likely to be more toxic due to their particle size, surface charge and characteristics compared to bulk materials and hence may pose a risk to the environment.

(3) Social Risks :

Nanotechnology supports new and easy solutions to many problems in agricultural, food processing, renewable energy and healthcare sectors and removes many existing jobs through improved and automated technology used in manufacturing and service sectors which contribute to loss of manufacturing and agricultural jobs. Such mass loss of jobs in primary and secondary sectors creates social inequalities. Nanotechnology will enable micro supercomputers on a very small scale, detection of minute amounts of substances, rapid analysis of genomes, and implantation of microchips into humans may lead to a darker side of violation of privacy. Though nanotechnology supports surveillance using nano-sensors extremely small cameras, people be afraid of the security and privacy of individuals by tracking their location and their instantaneous behaviour. Such a negative perception of nanotechnology in society may result in questionable marketing decisions and hindrance in the speed of technology acceptance.

(4) Economic Risks :

Nanotechnology supports huge agricultural production, artificial food at low cost, renewable energy for everyone, low cost shelter, long life automobiles, low cost healthcare services and these innovations in the society leads economic market crashes due to potential lower demand to oil & gas resources as well as due to crashed market for precious metals like silver, gold, or diamonds, etc due to artificial reproduction of such things using molecular manipulation techniques. All this leads to crash of economic market and hence many industry performances.

(5) Predictive Green Goo :

Another potential danger predicted recently due to nanotechnology advances is that with time progress with nanotechnology advancement, a stage may reach where nanobots will become commonplace in society and with artificial intelligence technology these nanobots may develop their own intelligence

and replicate in an uncontrolled manner such a way that one day the earth may overrun by these nanobots. This hypothetical situation is called a gray goo effect. Alternatively, one day there is a risk on the entire planet that may overrun by nanoengineered organisms called green goo.
The above nanotechnology risks are in turn hindering the progress and investment of financial resources on nanotechnology research by many countries' governments.

8. GREEN AND ECO-FRIENDLY NANOTECHNOLOGY :

Ideally, nanomaterial development should be incorporate a safety-by-design approach, as there is a marketing edge for nano-enabled products with a reduced potential impact on health and the environment. Such green nanotechnology solutions play a major role in realizing sustainable development goals and eliminate the threat of the technification of development processes. Green Technology (GT) is an environmental healing technology that reduces environmental damages created by the products and technologies for peoples' conveniences. It is believed that GT promises to augment farm profitability while reducing environmental degradation and conserving natural resources Green technologies are sustainable technologies which will not create footprint when used for various processes/applications [92]. Green technologies support the use of natural organic resources and avoid the production of green gasses. They also consume less resources and do not support to increase the entropy of the universe. Green technologies do not support any kind of environmental degradation. They support the automation of every process and hence avoid human intervention. Since they do not support environmental degradation and contribute to creating the footprint, they are sustainable, improve the lifestyle of the people, and contribute to human comfortability. The major technologies used in the present day like Aircraft technology, Automobile technology, Biotechnology, Computer technology, Telecommunication technology, Education technology, Internet technology, Renewable energy technology, Atomic & Nuclear technology, Nanotechnology, Space technology, etc. can be made green using the principle of green technology [93-102]. Nanotechnology predicted as to be pioneering technology of the 21st century, if modified as a green technology, will be accepted by every user and play an important role in solving problems of society at both basic and advanced levels. The objectives of green nanotechnology in some of the basic and advanced fields of society are listed in table 4.

Table 4 : Objectives of green nanotechnology in various areas of society

S. No.	Area	Objectives of green nanotechnology
1	Agriculture	To avoid environmental degradation in nanotechnology supported agricultural processes including pest control.
2	Food Processing	To eliminate poisonous contents in food and to avoid green gas emission and environmental degradation in all food packaging processes which are supported by green nanotechnology.
3	Potable water	To develop large scale filters for water purification and sea water desalination through green nanotechnological processes without environmental degradation.
4	Sustainable Energy	To develop green nanotechnological processes for harvesting potential natural energy sources to generate required energy to human civilization without degrading environment.
5	Consumer products	To produce a variety of new generation consumer products using green nanotechnology without side effects and without

		degrading environment in any manner during production, packaging, and in actual use by consumers.
6	Automobiles	To produce energy efficient, zero emissions, durable automobiles using renewable energy processes based on green nanotechnology.
7	Construction	To build environmentally friendly, energy efficient, smart buildings with the help of green nanotechnological processes.
8	Industrial Automation	To develop industrial processes which are environmentally friendly, no green gas emission, recyclable waste products using green nanotechnology.
9	Computer and Information Communication	To develop and utilize environmentally friendly, recyclable electronic and computer components which use renewable energy and efficient performance using green nanotechnology.
10	Education	Use of green nanotechnology in all hardware required in education services.
11	Health	Use of green nanotechnology with green processes in all health and medical services.
12	Aircraft & Space Travel	Use of green energy and green nanomaterials and environmentally friendly nanotechnological processes in air and space travel.

There are many green synthesis protocols which use green chemistry principles for preparation of nanoparticles and hence nanomaterials compared to conventional methods [103-104]. This include:
(1) Non-hazardous naturally occurring materials to use as starting material using bottom-up approach,
(2) Recyclability and reuse of magnetic nanoparticles in nano-catalysis applications
(3) Metal nanoparticles can be prepared using natural anti-oxidant agents like poly phenols from Tea or wine or agricultural residues.
(4) Nanoparticles prepared using mild reaction conditions in the facile synthesis display educed toxicity and suitable for environmental remediation applications.
(5) Metal nanoparticles with antibacterial activities can be synthesised using biogenetic reduction by plants using reducing agents involved include various water-soluble metabolite compounds.
(6) Silver and gold nanoparticles which have applications in many industries are prepared using plant-based green chemistry preparation principles.
(7) Many crystalline inorganic compounds are prepared using bottom-up low temperature methods such as hydro/solvothermal synthesis, template-assisted approaches, nucleation, and growth in solution/suspension, microemulsion, miniemulsion, etc.
(8) Microbial synthesis of nanoparticles using bacteria, fungi, and viruses; phototrophic eukaryotes, including plants, diatoms, and algae; heterotrophic human cell lines and some other biological agents fall under green synthesis of nanoparticles as eco-friendly, cost-effective, and simple approaches.
(9) Microwave assisted organic synthesis methods are used to prepare metal nanoparticles

Hence, nanostructures and nanocomposites of metals and metal oxides like, Au, Ag, Al, Eu, Co, Pd, Pt, Fe, C_{60}, CdS, ZnO, Bi_2O_3, TiO_2, $NiFe_2O_4$, etc. are prepared using bottom-up methods like sol-gel

method or chemical reduction methods using natural sources like plants, fungi, etc. These green chemistry preparation processes of nanomaterials and nanostructures boost the green nanotechnology movement and gives confidence to industries to promote nanotechnology-based products and services.

9. PROSPECTS OF GREEN NANOTECHNOLOGY IN PRIMARY INDUSTRY SECTOR :

The primary industry sector in the economy includes all industries that are involved in the production and extraction of raw materials from nature such as farming, mining, oil & natural gas, forestry, fishing, etc. The primary industry sector constitutes a larger portion of the economy in the entire world with more contributions from developing countries. Green nanotechnology principles and processes have immense advantages and benefits in the primary industry sector compared to its constraints. Table 5 lists opportunities and challenges for green nanotechnology-based innovations in the primary industry sector.

Table 5 : Green nanotechnology based innovations in Primary Industry Sector

S. No.	Natural Resources Industries	Opportunities (O) and Challenges (C) of Green Nanotechnology
1	Agriculture	O: Use of nanofertilizers, nanopesticides, nanobiosensors, and nano-enabled remediation are used in precision forming and biotic and abiotic remediation, for controlled release of nutrients to targeted soils, soil biota, soil organic matter and plant morphological and physiological responses, aimed to obtain their fullest biological efficacy without overdosage. Nano-sensors and nano-remediation methods may detect and remove environmental contaminants.
		C: There is limited knowledge concerning nanomaterial biosafety, adverse effects, fate, and acquired biological reactivity once dispersed into the environment, requires further scientific efforts to assess possible nano-agricultural risks. Lack of adequate risk management strategies for workers, occupational safety practices, and policies, as well as to develop a responsible regulatory consensus.
2	Forestry	O: Green nanotechnology has the ability to reduce carbon footprints of petroleum-based products by means of renewable forest-based nanocellulose. Nanocellulose is considered important material for research and development of plastics, coatings, sensors, electronics, automobile body and aerospace materials, medical implants, and body armor so that future day plastics, cellular telephones, medical implants, body armor, and flexible displays will be produced as forest products.
		C: To achieve improvement in the performance-to-weight ratio of paper and packaging products through green nanotechnology to create features such as optical, electronic, barrier, sensing thermal, and surface texture.

3	Mining	O: Use of nanosized vessels to recover valuable minerals that end up in the waste. Use of green nanomaterials like graphene coatings on drill bits that perform borehole drilling to increase effectiveness and longevity. Use of green nanomaterial for lubrication for all the mechanical parts heavy-duty machinery to work optimally. Use of green nanotechnology allows us to isolate gold from raw materials in a selective manner instead of using cyanide.
		C: To prove that the nanoparticles prepared through the green route used in mining are not have side effects for mining workers and the environment.
4	Fisheries	O: Green nanotechnology can revolutionize fisheries and aquaculture industry with new tools like rapid disease detection, to speed up the absorption of drugs like hormones, vaccines, and nutrients to fish, and by using antibacterial nanocoatings, shelf life of fish and shellfish may be improved. Green supply chain using nanotechnology can decrease supply chain time between origin to destination. Nanotechnological applications in fisheries also include antibacterial surfaces in the aquaculture system, nanodelivery of veterinary products in fish food using porous nanostructures, and nanosensors for detecting pathogens in the water including removing microbes, organic chemicals, and metals.
		C: Proper methods of measurement of environmental effects and the surveillance of nanomaterials in products, especially food such as fish fillets, are needed.
5	Oil & Natural Gas	O: Green nanotechnology provides nanomaterials to be used ass drilling fluids and enhanced oil recovery in addition to other applications including cementing and well stimulation to enhance well productivity.
		C: Economic feasibility of nanoparticle to be used and their commercial availability. To know the hazardous nature of nanoparticles on health, environment, and safety, and predicted severe health issues.

10. PROSPECTS OF GREEN NANOTECHNOLOGY (GNT) IN SECONDARY INDUSTRY SECTOR :

The secondary industry sector in an economy includes secondary processing of raw materials as inputs into various usable products using different types of machines. The output of the secondary industries is manufactured or assembled finished products which are tangible in nature. Green nanotechnology principles and processes have direct implications of business performance in the secondary industry sector. Table 6 lists opportunities and challenges for green nanotechnology-based innovations in some of the secondary industry sectors.

Table 6 : Nanotechnology based manufacturing innovations in Secondary Industry Sector

S. No.	Manufacturing Industries	Opportunities (O) and Challenges (C) of Green Nanotechnology
1	Potable water sector	O: Green nanotechnology can be used to convert impure water and seawater into potable water. The nanofilters made by nanomembranes can remove all kinds of water contaminants including turbidity, oil, bacteria, viruses, and organic contaminants from impure water or salt from seawater.
		C: Implementation of nanotechnology-enabled alternatives systematically using optimum nanomembranes for the conversion of impure water into potable water throughout the world in a fixed timeframe.
2	Environment Cleaning sector	O: Green nanotechnology products, processes, and applications are capable to clean degraded environments including air cleaning, water cleaning, and sound cleaning and controls climate change by reducing greenhouse gases and hazardous wastes.
		C: Implementation of systematically designed low cost renewable energy supported nanotechnology-based environment purifying system in every country within a fixed timeline.
3	Food & Food Processing sector	O: Use of green nanotechnology in food protection and delivery to targeted sites, improving food flavour, to encapsulate nutrients such as vitamins, adding antibacterial green nanoparticles into food for enhancement of shelf life, sensing the contamination, improving food storage, tracking, training, brand protection, etc.
		C: Identifying the potential harm of nanomaterials to human beings due to added green nanomaterials to food and food packaging applications.
4	Renewable Energy sector	O: Use of green nanotechnology for renewable energy generation, transmission, storage, efficient lighting, and energy management systems at low cost.
		C: Identifying optimum nanomaterial for a particular application, reduction of cost toward zero, improving efficiency toward 100%, optimization of storage properties of nanotechnology-based storage device, etc.
5	Construction industry sector	O: Green nanotechnology allows to improve the properties of construction materials including cement with the addition of nanoparticles will lead to stronger, more durable, self-healing, air purifying, fire resistant, easy to clean, optimum heat & noise insulation, and quick compacting concrete.

		C: Challenges include unknown environmental, health and safety risks, uncertainty concerning the market and consumer acceptance.
6	Consumer goods industry sector	O: Green nanotechnology has made an impact on fast consumer goods like textile and fabrics, cosmetics & skin cares, sporting goods, cleaning products, furniture, home appliances, etc in terms of durability, production cost, enhanced features, security, etc.
		C: Challenges include technology transfer, government approvals, consumer acceptance & awareness, negative propaganda and lobby of existing conventional manufacturers, etc.
7	Automobile industry	O: Green nanotechnology supported lightweight but stronger automobile components, increased performance with long mileage, durable tyres, self-repairing, long life batteries, renewable energy through nanopaints, which lead to cleaner, quieter, and more pleasant automobiles.
		C: Commercialization of green nanomaterials, nanocomponents, and nanosystems related to automobiles. Country government support to create awareness among automobile manufacturers and customers.
8	Medical equipment & Drug synthesis,	O: Green nanotechnology supports to revolutionize drug manufacturing, targeted drug delivery, medical diagnostics, regenerative medicines,
		C: Worldwide acceptance of new drugs, treatment procedures, and regulatory practices take time for global usage. Monitoring side effects and attitudes of medical practitioners also hinder the medical treatments in the health science regime.
9	Electrical, Electronics and computer industry sector	O: Green nanotechnology based high speed and miniature sized communication devices and computation devices, high density memory chips, nano-sensors, etc for ubiquitous communication, computation, embedded wearable electronics, and entertainment.
		C: Complexity involved in fabricating nanoelectronics devices and the resistance of many companies to shift from silicon-based electronics to molecular nanomaterials-based devices.
10	Aerospace & Defense sector	O: Green nanotechnology supports miniaturized drones or a swarm of artificial bees to provide additional awareness and visibility. The miniaturized bots equipped with artificial intelligence support give information on the battlefield situations. Hence, GNT with nanosatellites, nano-battlesuit, nanosensors, nano-drones, nanosystems planted in human bodies, and nano-nuclear chemical & biological weapons will give the upper hand in defense and aerospace sector against conventional technologies.

		C: Technology transfer, skilled human resource, Huge initial investment, awareness at decision making level, procrastination of decisions.

11. PROSPECTS OF GREEN NANOTECHNOLOGY IN TERTIARY INDUSTRY SECTOR :

The tertiary industry sector in an economy includes business which offers various services to consumers. These services are usually intangible in nature and produce high gross domestic products (GDP) and employment. Green nanotechnology affects the service industry sector both directly and indirectly. Green nanotechnology principles and processes have implications in future performances in this industry sector. Table 7 lists opportunities and challenges for green nanotechnology-based innovations in the tertiary industry sector.

Table 7 : Nanotechnology based service innovations in the Tertiary Industry Sector

S. No.	Service Industries	Opportunities (O) and Challenges (C) of Green Nanotechnology
1	Advertising industry	O: Green nanotechnology provides special effect paints and displays which change their colour at different light intensity levels and hence at a different time of the day.
		C: Commercialisation of such technology, Cost against existing systems/models, and durability are yet to be tested.
2	Education industry	O: Green nanotechnology as a career option, Improving and innovations in educational technology through higher quality and low-cost internet as well as display devices leading to ubiquitous online education.
		C: Challenges include, complexity involves in technology and initial investment cost.
3	E-Commerce industry	O: Green nanotechnology supports the identification of counterfeit goods. Certified QR codes and tracking devices supported by nanotechnology can be utilized for product packaging.
		C: Creating awareness on the use of such technology with identity benefits to many products consumes time.
4	Entertainment industry	O: Green nanotechnology supports to improve the efficiencies of digital entertainment instruments and their durability. It also improves the speed and reachability of internet signals for high speed online video games.
		C: Cost and creating awareness are two major challenges for nanotechnology-based entertainment services.
5	Fashion industry	Green nanotechnology embedded fabrics can be designed to resist liquids, fight off wrinkles, quick drying, and breathe. Also, for the killing of microbes in cloths, coating that repels water and stain-producing liquids, antistatic nanoparticles to discharge

		accumulated static charge, new designs & patterns on fabrics and fashion equipment, etc.
		C: Awareness creation and reachability of GNT features in the industry.
6	Financial services industry	O: Huge investment in mega-technology will facilitate the banking sector and drive economic growth. The financial industry will have a key role in the transfer of technology from research centres to various industries. GNT provides technological support for authentic and secured financial transactions.
		C: Slow technology transfer, Delay in investment decisions, Financial constraints for start-ups, effective utilization of government budgets, etc.
7	Healthcare industry	O: Disease control by means of disease diagnostics, prophylactics, and treatment of diseases. Nanoprobes, nanosensors have the potential for prevention and control of diseases. GNT based organ regeneration and lifespan expansion are also possible.
		C: Use of GNT in health care may raise concern on regulation, transparency, patient privacy, and consent, etc.
8	Hospitality industry	O: Food preservation with original taste; Self-cleaning of floors, walls, fabrics, and furniture; bacteria-repellant bathroom surfaces; bed sheets that resist wear and soil and adjust for comfort or a pillowcase that glows when a guest reads in bed.
		C: Cost of technology during the initial investment time is certainly high.
9	Insurance industry	O: Insurance industry sees GNT as a big opportunity for its future survival and growth. Nanotechnology companies might adopt insurance coverage to reduce their risks and liability for new futuristic business in every industry sector
		C: The fundamental difficulty in making risk assessment unless quantifiable statistical data are readily available, and hence probability and severity are difficult to calculate.
10	Print & Media industry	O: GNT has applications from printing inks to digital printing processes, videography, wearable audio recording devices, and high speed online electronic and optical communication device.
		C: Slow technology transfer & Higher cost for early entrants.
11	Online services industry	O: GNT supports online ubiquitous services through 5G and future 6G technology where it can offer audio, video, smell, taste, and touch feelings of products and services for online selections. Using

		smart and artificial intelligence enabled computers, mass customization of online services is possible.
		C: Slow penetration to the market due to early breathing problems.
12	Tourism industry	O: GNT based attractive display screens at tourism centres, airports, and various other locations to provide quick Information.
		C: Cost factor until mass usage.
13	Security Services	O: Tagging and tracking, monitoring, advancing sensors technology, improved RFID technology in body armour, combating fraud with nanoparticle-based inks.
		C: Integrating nanotechnology with ICCT for specific services.
14	Coating Services industry	O: Coating service, based purely on nano coating on surfaces/devices for specific purposes.
		C: Attractive for large scale coatings only based on cost-benefit analysis.
15	Event management industry	O: GNT based electronic decorations, waste management, food and beverage quality management, music service, clothing service, etc.
		C: Coordination with technology provider and event management team.
16	Smart City Services Industry	O: Green nanomaterial enabled the network to provide a backbone for smart city communications using 5G technology. Inclusion of nanotechnology in smart city solutions along with Information technology solutions, power plant, water treatment, road infrastructure, ait pollution, etc.
		C: Delay in the realization of smart cities by governments in developed and developing countries.

12. PROSPECTS OF GREEN NANOTECHNOLOGY IN QUATERNARY INDUSTRY SECTOR :

The quaternary industry sector in the economy includes the activities based on the intellectual or knowledge-based part of the economy. This sector is found in only most advanced countries in which through research and development, latest information communication and computation technology (ICCT) and typically includes services such as information generation and sharing, information technology (communication & computing), consultation, education, research and development, and other knowledge-based services supported by technology. The important ICCT underlying technologies which work with green nanotechnology to provide intelligent services are artificial intelligence, 3D printing, cloud computing, internet of things, quantum computing, information storage technology, mobile business technologies, and online education technologies. Green nanotechnology being general purpose technology of the 21st century supports ICCT underlying technologies as another set general purpose technologies to develop super-intelligent machines and super-human beings when these technologies get saturated [90].

13. OPPORTUNITIES AND CHALLENGES FOR GREEN NANOTECHNOLOGY TO ACHIEVE SUSTAINABLE DEVELOPMENT GOALS :

Nanotechnology offers a plethora of new materials for different industries and industry sectors. Though public perception is generally supportive of nanotechnology, some risk analysis of the potential long-term effects of green routed manufactured nanomaterials in human food is required. In different industry sectors, the exposure risk would relate to different aspects and it is a challenge to the scientist and engineers as well as local governments while managing the nanotechnology innovations. This also needs to arrange some public awareness to explain the uses of nanotechnology by all industry sectors to explain the benefits and risks to the consumers. The exact number of available nanomaterials naturally available as well as man-made in the environment including the oceans are not understood and the fate and behaviour of manufactured nanomaterials in important systems, such as the oceans, are poorly understood. The design of nanomaterials should be according to the principles of green nanotechnology that would complement and support current regulations of the government and to address the predicted risk while fostering the sustainable development of nanotechnology as green technology.

While discussing about opportunities and challenges of green nanotechnology and nanomaterials as general purpose technology to solve many problems in the primary industry sector, secondary industry sector, tertiary industry sector, and quaternary industry sector, it is found that nanotechnology is a boon to mankind and gives incredible power to human beings to improve the comfortability and quality of life. While comparing the United Nations sustainable development goals with green nanotechnology (GNT) opportunities, 12 goals out of 17 goals can be realized by using green nanotechnology. Five goals can be realized using ICCT underlying technologies and one goal of reduced inequalities among Countries is not directly related to technological innovations. The possibility of using green nanotechnology processes/ nanotechnology systems in solving 17 goals of global sustainable development is shown in table 8.

Table 8 : SD goals, suitable technologies and focus on different industry sector to achieve them

Goal No.	Focus Issue	Technology	Focus of Technological solutions in different industry sectors
1	Reduce Poverty	NT	Green nanotechnology in Primary sector with focus on agriculture industry.
2	Reduce Hunger	NT	Green nanotechnology with a focus on food preservation, transportation and even preparation of artificial food.
3	Health & Well-Being	NT	Green nanotechnology in healthcare and environment cleaning.
4	Quality Higher Education	ICCT	Education technology using ICCT and nanotechnology in the tertiary sector.
5	Gender Equality	ICCT	Awareness and equal opportunity creation using ICCT based education.
6	Clean Water & Sanitation	NT	Green nanotechnology in primary and secondary industry sectors.
7	Affordable renewable energy	NT	Green nanotechnology for highly efficient renewable energy generation and storage.

8	Decent Employment	NT & ICCT	Green nanotechnology together with ICCT created skilled jobs and employment.
9	Sustainable Industrialization	NT & ICCT	Green nanotechnology together with ICCT provides industry 4.0 and industry 5.0 based mass customization and total automation in all industry sectors.
10	Reduced Inequalities among Countries	-	Through technology transfer and cooperation between the countries through free trade.
11	Safe & Sustainable Cities & Communities	ICCT & NT	Green nanotechnology together ICCT supports to create smart cities integrated industrial facilities.
12	Ensure sustainable Production & Consumption	NT & ICCT	Green nanotechnology together with artificial intelligence and IoT supports sustainable production and consumption of essential commodities.
13	Combat on Climate Change	NT	Green nanotechnology supports to control environmental degradation and provides the optimum solution to clean the environment and helps to combat climate change.
14	Conserve Ocean & Marine Resources	NT	Green nanotechnology is capable enough to clean the ocean to conserve Marine resources.
15	Protect life on Land	NT	Green nanotechnology in the healthcare sector, strong shelter, and pollution free clean environment through nanotechnology can protect life on the planet.
16	Ensure Peace and Justice	ICCT	Communicate & Collaborate using ICCT for peace and prosperity.
17	Global Partnership for Sustainability	ICCT	Communicate & Collaborate using ICCT for resource sharing.

The nanotechnology solutions in different industry sectors are planned by ensuring nanoscale materials are designed and developed with human health and the global environment in mind, and hence further fears on sustainability due to degradable environmental concerns are unnecessary for future years [105-106]. To accelerate the development of green nanotechnology, countries should consider the following steps:

(1) Educating the people and entrepreneurs to create a supportive environment in society to accept new technology products.
(2) Assessment of green nanotechnology implications to gauge the trade-off between benefits and constraints for nanoproducts and their existing counterparts.
(3) Develop a performance standard globally for green nanotechnology products for the producers and users.
(4) Branding green nano products and services globally by creating awareness in every country to use and to support to realize the sustainable development goals of the United Nations.
(5) Country governments should encourage the production and use of green nanotechnology products and services by providing tax relaxation and other financial incentives for the initial few years. This will accelerate the penetration of green nanotechnology products and services development and usage in the country.
(6) Government support for Open innovation without patent rights leads to wide production and marketing of green nanotechnology products and services by many companies in different industry sectors. A systematic rewarding policy should be developed to honour such an open innovation.
(7) Accelerated Focus on general purpose technology development through national technology policy to provide more resources and encouragement for researchers and investors.
(8) Government and Nongovernment organizations (NGO) efforts on creating awareness programmes on the advantages of green nano products and risk prevention strategies through the design of safer and green processes that make them.

The proactive policies of government and industry sectors to encourage investors and development of skilled human resources. The responsible approach of government, industries, organizations, and individuals in developing green and eco-friendly nanotechnology as a technological tool will enable more sustainable products and processes for the next industrial revolution to realize the United Nations Sustainable Development Goals.

14. CONCLUSION :

Converting nanotechnology into green and eco-friendly nanotechnology by means of using bottom-up preparation techniques of green chemistry allows us to decrease the risks associated with it to various industrial applications and resembles the many characteristics of ideal technology [89]. Being a general-purpose technology with characteristics like pervasiveness, improvement, and innovative opportunities, nanotechnology has its roots and branches in almost all parts of science and technology applications in society. The fear of adverse effects of nanomaterials on user health and environment is also possible to take care by choosing green synthesis methods at room temperature processes. The United Nations identified 17 sustainable development goals (SDG) in the year 2015, for global prospectus of humanity as systematic development objectives to be realized by 2030 with a timeframe of 15 years. These SDG goals can be realized using two general purpose technologies of the 21st century that include Nanotechnology (NT) and Information Communication & Computation Technology (ICCT), in which nanotechnology has a major role to support 12 goals for realization. The opportunities and challenges of green nanotechnology in major part of primary, secondary, tertiary, and quaternary industry sectors encourages and accelerates the growth and acceptance of technology by enhancing investments and support nanotechnology usage by every country.

REFERENCES :

[1] Aithal, P. S. & Shubhrajyotsna Aithal (October 2019). Management of Universal Technologies & their Industry Implications. *Proceedings of International Conference on Emerging Trends in Management, IT and Education*, *1*(2), pp. 318-328. ISBN No.: 978-87-941751-2-4. DOI : https://doi.org/10.5281/zenodo.3559719.

[2] Aithal, P. S. and Shubhrajyotsna Aithal (2018). Study of various General-Purpose Technologies and their contribution towards developing Sustainable Society. *International Journal of Management, Technology, and Social Sciences (IJMTS)*, *3*(2), 16-33.

[3] Aithal, P. S. (2016). Nanotechnology Innovations & Business Opportunities: A Review. *International Journal of Management, IT and Engineering (IJMIE)*, *6*(1), 182-204.

[4] Aithal P. S., and Shubhrajyotsna Aithal (2015). Managing Anticipated Breakthrough Technologies of 21st Century - A Review. *International Journal of Research & Development in Technology and Management Sciences*, *21*(6), 112 - 133.

[5] Aithal, P. S. and Shubrajyotsna Aithal (2016). Nanotechnology Innovations and Commercialization – Opportunities, Challenges & Reasons for Delay. *International Journal of Engineering and Manufacturing (IJEM)*, 6(6), 15-25.

[6] Renn, O., Roco, M. (2006). White paper no.2 Nanotechnology risk governance. *International Risk Governance Council*, Geneva, Switzerland. p.103.

[7] Jaiswal, S., & Mojahid, A. (2020). Innovation in Society through Green\Eco-Friendly Technology. *Journal for Modern Trends in Science and Technology*, *6*(01), 37-43.

[8] Aithal, P. S. and Shubhrajyotsna Aithal, (2016). Opportunities & Challenges for Green Technology in 21st Century. *International Journal of Current Research and Modern Education (IJCRME)*, *1*(1), 818-828.

[9] Ray, P. C., Yu, H., & Fu, P. P. (2009). Toxicity and environmental risks of nanomaterials: challenges and future needs. *Journal of Environmental Science and Health Part C*, *27*(1), 1-35.

[10] Batley, G. E., Kirby, J. K., & McLaughlin, M. J. (2013). Fate and risks of nanomaterials in aquatic and terrestrial environments. *Accounts of chemical research*, *46*(3), 854-862.

[11] Coll, C., Notter, D., Gottschalk, F., Sun, T., Som, C., & Nowack, B. (2016). Probabilistic environmental risk assessment of five nanomaterials (nano-TiO2, nano-Ag, nano-ZnO, CNT, and fullerenes). *Nanotoxicology*, *10*(4), 436-444.

[12] Lanone, S., & Boczkowski, J. (2006). Biomedical applications and potential health risks of nanomaterials: molecular mechanisms. *Current molecular medicine*, *6*(6), 651-663.

[13] Medina-Reyes, E. I., Garcia-Viacobo, D., Carrero-Martinez, F. A., & Chirino, Y. I. (2017). Applications and risks of nanomaterials used in regenerative medicine, delivery systems, theranostics, and therapy. *Critical Reviews in Therapeutic Drug Carrier Systems*, *34*(1), 35-61.

[14] Hristozov, D., Gottardo, S., Semenzin, E., Oomen, A., Bos, P., Peijnenburg, W., ... & Scott-Fordsmand, J. J. (2016). Frameworks and tools for risk assessment of manufactured nanomaterials. *Environment international*, *95*, 36-53.

[15] Rezaei, A., & Kamali, A. R. (2018). Green production of carbon nanomaterials in molten salts, mechanisms and applications. *Diamond and Related Materials*, *83*, 146-161.

[16] Geraldes, A. N., da Silva, A. A., Leal, J., Estrada-Villegas, G. M., Lincopan, N., Katti, K. V., & Lugão, A. B. (2016). Green nanotechnology from plant extracts: synthesis and characterization of gold nanoparticles. *Advances in Nanoparticles*, *5*(3), 176-185.

[17] Ortiz de Zárate, D., García-Meca, C., Pinilla-Cienfuegos, E., Ayúcar, J. A., Griol, A., Bellières, L., ... & Martí, J. (2020). Green and Sustainable Manufacture of Ultrapure Engineered Nanomaterials. *Nanomaterials*, *10*(3), 466-480.

[18] Saif, S., Tahir, A., & Chen, Y. (2016). Green synthesis of iron nanoparticles and their environmental applications and implications. *Nanomaterials*, *6*(11), 209-235.

[19] Al-Dhabi, N. A., & Valan Arasu, M. (2018). Environmentally-friendly green approach for the production of zinc oxide nanoparticles and their anti-fungal, ovicidal, and larvicidal properties. *Nanomaterials*, *8*(7), 500-513.

[20] Bhosale, R. R., Kulkarni, A. S., Gilda, S. S., Aloorkar, N. H., Osmani, R. A., & Harkare, B. R. (2014). Innovative eco-friendly approaches for green synthesis of silver nanoparticles. *International Journal of Pharmaceutical Sciences and Nanotechnology*, *7*(1), 2328-2337.

[21] Rai, M., & Ingle, A. (2012). Role of nanotechnology in agriculture with special reference to management of insect pests. *Applied microbiology and biotechnology*, *94*(2), 287-293.

[22] Yashveer, S., Singh, V., Kaswan, V., Kaushik, A., & Tokas, J. (2014). Green biotechnology, nanotechnology and bio-fortification: perspectives on novel environment-friendly crop improvement strategies. *Biotechnology and Genetic Engineering Reviews*, *30*(2), 113-126.

[23] Jain, A., Ranjan, S., Dasgupta, N., & Ramalingam, C. (2018). Nanomaterials in food and agriculture: an overview on their safety concerns and regulatory issues. *Critical reviews in food science and nutrition*, *58*(2), 297-317.

[24] Omanović-Mikličanina, E., & Maksimović, M. (2016). Nanosensors applications in agriculture and food industry. *Bull Chem Technol Bosnia Herzegovina*, *47*, 59-70.

[25] Mazzaglia, A., Fortunati, E., Kenny, J. M., Torre, L., & Balestra, G. M. (2017). Nanomaterials in plant protection. *Nanotechnology in Agriculture and Food Science*, *7*, 115-133.

[26] Huang, Y., Mei, L., Chen, X., & Wang, Q. (2018). Recent developments in food packaging based on nanomaterials. *Nanomaterials*, *8*(10), 830.

[27] Duhan, J. S., Kumar, R., Kumar, N., Kaur, P., Nehra, K., & Duhan, S. (2017). Nanotechnology: The new perspective in precision agriculture. *Biotechnology Reports*, *15*, 11-23.

[28] Aithal, S., & Aithal, P. S. (2018). Concept of Ideal Water Purifier System to Produce Potable Water and its Realization Opportunities using Nanotechnology. *International Journal of Applied Engineering and Management Letters (IJAEML)*, *2*(2), 8-26.

[29] Patanjali, P., Singh, R., Kumar, A., & Chaudhary, P. (2019). Nanotechnology for water treatment: A green approach. In *Green Synthesis, Characterization and Applications of Nanoparticles* (pp. 485-512). Elsevier.

[30] Gautam, P. K., Singh, A., Misra, K., Sahoo, A. K., & Samanta, S. K. (2019). Synthesis and applications of biogenic nanomaterials in drinking and wastewater treatment. *Journal of environmental management*, *231*, 734-748.

[31] Bishoge, O. K., Zhang, L., Suntu, S. L., Jin, H., Zewde, A. A., & Qi, Z. (2018). Remediation of water and wastewater by using engineered nanomaterials: a review. *Journal of Environmental Science and Health, Part A*, *53*(6), 537-554.

[32] Kamali, M., Persson, K. M., Costa, M. E., & Capela, I. (2019). Sustainability criteria for assessing nanotechnology applicability in industrial wastewater treatment: Current status and future outlook. *Environment international*, *125*, 261-276.

[33] Teow, Y. H., & Mohammad, A. W. (2019). New generation nanomaterials for water desalination: a review. *Desalination*, *451*, 2-17.

[34] Adeleye, A. S., Conway, J. R., Garner, K., Huang, Y., Su, Y., & Keller, A. A. (2016). Engineered nanomaterials for water treatment and remediation: Costs, benefits, and applicability. *Chemical Engineering Journal*, *286*, 640-662.

[35] Sivaraj, R., Salam, H. A., Rajiv, P., & Rajendran, V. (2015). Green Nanotechnology: The Solution to Sustainable Development of Environment. In *Environmental Sustainability* (pp. 311-324). Springer, New Delhi.

[36] Aithal, P. S. & Shubhrajyotsna Aithal, (2016). Nanotechnology Innovations & Business Opportunities in Renewable Energy Sector. *International Journal of Engineering Research and Modern Education (IJERME)*, *1*(1), 674- 692.

[37] Aithal, P. S. & Shubhrajyotsna Aithal (2018). The Concept & Characteristics of Ideal Energy System and its Realization Constraints. *International Journal of Applied Engineering and Management Letters (IJAEML)*, *2*(2), 127-137.

[38] Shubhrajyotsna Aithal & Aithal, P. S. (2018). The Realization Opportunity of Ideal Energy System using Nanotechnology Based Research and Innovations. *International Journal of Advanced Trends in Engineering and Technology*, *3*(2), 1-15.

[39] Moore, E. A., Babbitt, C. W., Gaustad, G., & Moore, S. T. (2018). Portfolio optimization of nanomaterial use in clean energy technologies. *Environmental science & technology*, *52*(7), 4440-4448.

[40] Guo, K. W. (2012). Green nanotechnology of trends in future energy: a review. *International journal of energy research*, *36*(1), 1-17.

[41] Pandey, G. (2018). Nanotechnology for achieving green-economy through sustainable energy. *thought*, *11*, 942-950.

[42] Choi, J. W., Wang, D., & Wang, D. (2016). Nanomaterials for energy conversion and storage. *ChemNanoMat*, *2*(7), 560-561.

[43] Qu, K., Wang, Y., Vasileff, A., Jiao, Y., Chen, H., & Zheng, Y. (2018). Polydopamine-inspired nanomaterials for energy conversion and storage. *Journal of Materials Chemistry A*, *6*(44), 21827-21846.

[44] Adesina, A. (2020). Nanomaterials in cementitious composites: review of durability performance. *Journal of Building Pathology and Rehabilitation*, *5*(1), 1-9.

[45] Peyvandi, A., Soroushian, P., Farhadi, N., & Balachandra, A. M. (2018). Evaluation of the reinforcement efficiency of low-cost graphite nanomaterials in high-performance concrete. *KSCE Journal of Civil Engineering*, *22*(10), 3875-3882.

[46] Kwalramani, M. A., & Syed, Z. I. (2018). Application of nanomaterials to enhance microstructure and mechanical properties of concrete. *International Journal of Integrated Engineering*, *10*(2).

[47] Ugwu, O. O., Arop, J. B., Nwoji, C. U., & Osadebe, N. N. (2013). Nanotechnology as a preventive engineering solution to highway infrastructure failures. *Journal of construction engineering and management*, *139*(8), 987-993.

[48] Sev, A., & Ezel, M. (2014). Nanotechnology innovations for the sustainable buildings of the future. *World Academy of Science, Engineering and Technology International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, *8*(8), 886-896.

[49] Oke, A. E., Aigbavboa, C. O., & Semenya, K. (2017). Energy savings and sustainable construction: examining the advantages of nanotechnology. *Energy Procedia*, *142*, 3839-3843.

[50] Yapar, E. A. & İNAL, Ö. (2012). Nanomaterials and cosmetics. *İstanbul Üniversitesi Eczacılık Fakültesi Dergisi*, *1*(42 (1)), 43-70.

[51] Srinivas, K. (2016). The current role of nanomaterials in cosmetics. *Journal of Chemical and Pharmaceutical Research*, *8*(5), 906-914.

[52] Masunaga, T. (2014). Nanomaterials in cosmetics--present situation and future. *Yakugaku zasshi: Journal of the Pharmaceutical Society of Japan*, *134*(1), 39.

[53] Cao, M., Li, J., Tang, J., Chen, C., & Zhao, Y. (2016). Gold nanomaterials in consumer cosmetics nanoproducts: analyses, characterization, and dermal safety assessment. *small*, *12*(39), 5488-5496.

[54] Bilal, M., & Iqbal, H. (2020). New Insights on Unique Features and Role of Nanostructured Materials in Cosmetics. *Cosmetics*, *7*(2), 24.

[55] Gajbhiye, S., & Sakharwade, S. (2016). Silver nanoparticles in cosmetics. *Journal of Cosmetics, Dermatological Sciences and Applications*, *6*(1), 48-53.

[56] Shalaby, M. N., & Saad, M. M. (2020). Advanced Material Engineering and Nanotechnology for Improving Sports Performance and Equipment. *International Journal of Psychosocial Rehabilitation*, *24*(10), 2314-2322.

[57] Mathew, J., Joy, J., & George, S. C. (2019). Potential applications of nanotechnology in transportation: A review. *Journal of King Saud University-Science*, *31*(4), 586-594.

[58] Lloyd, S. M., & Lave, L. B. (2003). Life cycle economic and environmental implications of using nanocomposites in automobiles. *Environmental Science & Technology*, *37*(15), 3458-3466.

[59] Aithal, P. S. & Shubrajyotsna Aithal, (2016). Nanotechnological Innovations & Business Environment for Indian Automobile Sector: A Futuristic Approach. *International Journal of Scientific Research and Modern Education (IJSRME)*, *1*(1), 296-307.

[60] Wallner, E., Sarma, D. H. R., Myers, B., Shah, S., Ihms, D., Chengalva, S., ... & Dykstra, C. (2010). *Nanotechnology applications in future automobiles* (No. 2010-01-1149). SAE Technical Paper. pp. 1-12. DOI: https://doi.org/10.4271/2010-01-1149.

[61] Gurjar, B. S., & Tyagi, P. (2015). Applications of Nanotechnology in Automobile Industry for Efficiency Enhancement and Energy saving-A Review. *International Journal of Interdisciplinary Research*, *2*(3), 1-7.

[62] Shafique, M., & Luo, X. (2019). Nanotechnology in transportation vehicles: an overview of its applications, environmental, health and safety concerns. *Materials*, *12*(15), 2493.

[63] Krishnan, A., Shandilya, S., HS, B., & Gupta, P. (2020). A Review on Applications of Carbon Nanotubes in Automobiles. *International Journal of Mechanical Engineering and Technology*, *11*(1), 204-210.

[64] Contado, C. (2015). Nanomaterials in consumer products: a challenging analytical problem. *Frontiers in chemistry*, *3*(48), 1-20.

[65] Hansen, S. F., Baun, A., Michelson, E. S., Kamper, A., Borling, P., & Stuer-Lauridsen, F. (2009). Nanomaterials in consumer products. In *Nanomaterials: Risks and Benefits* (pp. 359-367). Springer, Dordrecht.

[66] Vance, M. E., Kuiken, T., Vejerano, E. P., McGinnis, S. P., Hochella Jr, M. F., Rejeski, D., & Hull, M. S. (2015). Nanotechnology in the real world: Redeveloping the nanomaterial consumer products inventory. *Beilstein journal of nanotechnology*, *6*(1), 1769-1780.

[67] Pak, Y. E. (2001, August). MEMS and nanotechnology research for the electronics industry. In *Smart Structures and Materials 2001: Smart Electronics and MEMS* (Vol. 4334, pp. 23-29). International Society for Optics and Photonics.

[68] Wu, W. (2017). Inorganic nanomaterials for printed electronics: a review. *Nanoscale*, *9*(22), 7342-7372.

[69] Moghaddam, H. K., Maraki, M. R., & Rajaei, A. (2020). Application of Carbon Nanotubes (CNT) on The Computer Science and Electrical Engineering: A Review. *International Journal of Reconfigurable and Embedded Systems*, *9*(1), 61-82.

[70] Tyagi, M., & Tyagi, D. (2014). Polymer nanocomposites and their applications in electronics industry. *Int. J. Electron. Electr. Eng*, *7*(6), 603-608.

[71] Vargas-Bernal, R., Herrera-Pérez, G., & Tecpoyotl-Torres, M. (2019). The Impact of Carbon Nanotubes and Graphene on Electronics Industry. In *Advanced Methodologies and Technologies in Digital Marketing and Entrepreneurship* (pp. 382-394). IGI Global.

[72] Anuhya, K. H., & Eunice, T. G. (2016). Potential Impact of Nanomaterials in Information and Communication Technologies. *Indian Journal of Research in Pharmacy and Biotechnology*, *4*(6), 267-270.

[73] Kardanmoghaddam, H., Maraki, M., & Rajaei, A. (2020). GRAPHENE-REINFORCED POLYMERIC NANOCOMPOSITES IN COMPUTER AND ELECTRONICS INDUSTRIES. *Facta Universitatis, Series: Electronics and Energetics*, *33*(3), 351-378.

[74] Chen, X., Akinwande, D., Lee, K. J., Close, G. F., Yasuda, S., Paul, B. C., ... & Wong, H. S. P. (2010). Fully integrated graphene and carbon nanotube interconnects for gigahertz high-speed CMOS electronics. *IEEE Transactions on Electron Devices*, *57*(11), 3137-3143.

[75] Ahn, E. C., Wong, H. S. P., & Pop, E. (2018). Carbon nanomaterials for non-volatile memories. *Nature Reviews Materials*, *3*(3), 1-15.

[76] Le Ferrand, H., Chabi, S., & Agarwala, S. (2020). 3D Assembly of Graphene Nanomaterials for Advanced Electronics. *Advanced Intelligent Systems*, *2*(5), 1-16.

[77] Thomas, S. P., Al-Mutairi, E. M., & De, S. K. (2013). Impact of nanomaterials on health and environment. *Arabian Journal for Science and Engineering*, *38*(3), 457-477.

[78] Wacker, M. G. (2014). Nanotherapeutics—product development along the "nanomaterial" discussion. *Journal of Pharmaceutical Sciences*, *103*(3), 777-784.

[79] Schulte, P. A., Geraci, C. L., Murashov, V., Kuempel, E. D., Zumwalde, R. D., Castranova, V., ... & Martinez, K. F. (2014). Occupational safety and health criteria for responsible development of nanotechnology. *Journal of Nanoparticle Research*, *16*(2153), 1-17.

[80] Gopi, S., Amalraj, A., & Thomas, S. (2016). Effective drug delivery system of biopolymers based on nanomaterials and hydrogels—a review. *Drug Des*, *5*(129), 2169-0138.

[81] Liang, X. J., Chen, C., Zhao, Y., Jia, L., & Wang, P. C. (2008). Biopharmaceutics and therapeutic potential of engineered nanomaterials. *Current drug metabolism*, *9*(8), 697-709.

[82] Arepalli, S., & Moloney, P. (2015). Engineered nanomaterials in aerospace. *MRS Bulletin*, *40*(10), 804-811.

[83] Rizakhanov, R. N., Polyanskiy, M. N., Malinovskaya, O. S., & Tsvetkova, E. V. (2012). CVD Facility for the Formation of Carbon Nanomaterials on a Space Station Board. *Fullerenes, Nanotubes and Carbon Nanostructures*, *20*(4-7), 482-486.

[84] Haynes, H., & Asmatulu, R. (2013). Nanotechnology safety in the aerospace industry. In *Nanotechnology Safety* (pp. 85-97). Elsevier.

[85] Levchenko, I., Xu, S., Teel, G., Mariotti, D., Walker, M. L. R., & Keidar, M. (2018). Recent progress and perspectives of space electric propulsion systems based on smart nanomaterials. *Nature communications*, *9*(1), 1-19.

[86] Carpinteri, A., & Pugno, N. (2008). Bio-inspired hierarchical nanomaterials for space applications. *Journal of the British Interplanetary Society*, *61*(8), 290-294.

[87] Novikov, L. S., & Voronina, E. N. (2017). Potential space applications of nanomaterials. In *Protection of Materials and Structures from the Space Environment* (pp. 139-147). Springer, Cham.

[88] Nilsson, M., Griggs, D., & Visbeck, M. (2016). Policy: map the interactions between Sustainable Development Goals. *Nature*, *534*(7607), 320-322.

[89] Aithal, P. S., & Shubhrajyotsna Aithal, (2015). Ideal Technology Concept & its Realization Opportunity using Nanotechnology. *International Journal of Application or Innovation in Engineering & Management (IJAIEM)*, *4*(2), 153 - 164.

[90] Aithal P. S. & Shubhrajyotsna Aithal (2018). Nanotechnology based Innovations and Human Life Comfortability –Are we Marching towards Immortality ? *International Journal of Applied Engineering and Management Letters (IJAEML)*, *2*(2), 71-86.

[91] Aithal, P. S., & Madhushree, L. M. (2019). Emerging Trends in ICCT as Universal Technology for Strategic Development of Industry Sectors. Chapter in a Book - IT and Computing for all the Domains and Professionals: The Emergence of Computer and Information Sciences, Edited by Paul, P. K., Bhuimali, A., Tiwary, K. S. and Aithal P. S. published by New Delhi Publishers, New Delhi. pp 1-26, ISBN: 978-93-88879-66-8.

[92] Aithal P. S., & Shubhrajyotsna Aithal, Nanotechnology Innovations and Commercialization – Opportunities, Challenges & Reasons for Delay. *Proceedings of National Conference on Changing Perspectives of Management, IT, and Social Sciences in Contemporary Environment,* Vol. 14, pp-1-12, ISBN 978-93-5265-6523.

[93] Sridhar Acharya P & Aithal, P. S. (2015). Innovations in Effective Management of Energy using Green Technology. *International Journal of Conceptions on Management and Social Sciences*, *3*(2), 18 - 22.

[94] Aithal, P. S and Priti Jeevan (2016). Strategic Rethinking of Management Education: Green MBA Model. *International Journal of Management, IT and Engineering (IJMIE)*, *6*(1), 55-73.

[95] Aithal, P. S., & Preethi Rao (2016). How Service Industries Can Transform themselves into Green Business Industries. *International Journal of Management Sciences and Business Research (IJMSBR)*, *5*(4), 150-158.

[96] Han, W., & Liu, L. C., (2009). Discussion on Green Education in Universities. *Journal of Daqing Normal University*, 1(1), 39-45.

[97] Guoliang Wu, (2011). A New Concept of Green Education: The Cultivation Model for Successful and Practical Talents. *International Forum of Teaching & Studies*, *7*(1), 45-48.

[98] Aithal, P. S. (2015). Concept of Ideal Business & Its Realization Using E-Business Model. *International Journal of Science and Research (IJSR)*, *4*(3), 1267 – 1274.

[99] Aithal, P. S. (2015). Mobile Business as an Optimum Model for Ideal Business. *International Journal of Management, IT and Engineering (IJMIE)*, *5*(7), 146-159.

[100] Aithal, P. S., & Shubhrajyotsna Aithal (2015). An Innovative Education Model to realize Ideal Education System. *International Journal of Scientific Research and Management (IJSRM),* 3(3), 2464 – 2469.

[101] Prithi Rao and Aithal P. S. (2016). Green Education Concepts & Strategies in Higher Education Model. *International Journal of Scientific Research and Modern Education (IJSRME)*, *1*(1), 793-802.

[102] Boye, J. I. & Arcand, Y. (2013). Current Trends in Green Technologies. *Food Production and Processing. Food Eng Rev.*, 5(1), 1-17.

[103] Varma, R. S. (2012). Greener approach to nanomaterials and their sustainable applications. *Current Opinion in Chemical Engineering*, *1*(2), 123-128.

[104] Silva L. P., Reis I. G., Bonatto C. C. (2015). Green Synthesis of Metal Nanoparticles by Plants: Current Trends and Challenges. In: Basiuk V., Basiuk E. (eds) Green Processes for Nanotechnology. Springer, Cham. pp. 259-275.

[105] Shubhrajyotsna Aithal & Aithal, P. S. (2020). Nanotechnology based Mega Machine Design for Large Scale Air Cleaning – Prospects and Challenges. *International Journal of Case Studies in Business, IT, and Education (IJCSBE),* 4(2), 250-269.

[106] Shubhrajyotsna Aithal & P. S. Aithal (2020). Cleaning the Environment using Nanotechnology – A Review based Mega-Machine Design. In "Environmental Information Sciences: With aspects on Allied Areas & other emerging interdisciplinary Environmental Concerns" edited by P.K. Paul et al. published by New Delhi Publishers, New Delhi, India, pp. 13-40. ISBN: 978-93-88879-91-0, DOI: https://doi.org/10.5281/zenodo.4243767

****