

Using green nanotechnology to develop smart cities, for a more sustainable future and a clean environment (A Review)

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ABSTRACT

The use of nanotechnology to improve the environmental sustainability of processes that result in negative externalities is known as "green nanotechnology". The phrase also refers to the use of nanotechnology products to improve sustainability. It also covers the production of environmentally friendly Nano products and their application to promote sustainability. Green nanotechnology is defined as the creation of clean technologies that "reduce the potential risks to both environmental and human health associated with the manufacture and use of nanotechnology, and encourage the replacement of existing products with new environmentally friendly Nano products throughout their life cycle." Nanotechnology is also considered one of the technologies of materials engineering, and these technologies are related to various sciences such as physics, chemical engineering, biomedical engineering, and mechanical engineering, which is a science specialized in the research and production of materials at the very small atomic level. The study of matter processing at the atomic and molecular level is the focus of the science known as nanotechnology. The creation of novel technologies and procedures with dimensions expressed in nanometers—one thousandth of a micrometer or one millionth of a millimeter—is the focus of nanotechnology. Typically, nanotechnology works with atomic clusters that range in size from five to a thousand atoms, or measurements between one and one hundred nanometers. Compared to bacteria and live cells, these dimensions are far smaller. So far, this technology is not specialized in biology, but rather is concerned with the qualities of materials, and its domains vary greatly from semiconductors to fully new technologies based on molecular self-assembly. This specificity in measurement is matched by the expansion in the nature of the materials utilized, as nanotechnology works with any processes or structures at the microscopic Nano level. Quantum limitation, which creates novel electromagnetic and optical phenomena for matter between the size of a molecule and the apparent size of a solid, is one example of such Nano scale phenomena. The Gibbs-Thomson effect, which is the drop in a substance's melting point when its size reaches the Nano scale, is another example of a Nano scale phenomenon. Carbon nanotubes are the most significant Nano scale structures.

Keywords: Sustainable development, Environmental sustainability, Carbon nanotubes, Green nanotechnology, Nanotechnology.

Introduction

Nanotechnology has recently come to be associated with sustainability and a broader "green" agenda. The manufacturing of the nanoparticles must be done in an environmentally responsible manner in order to expand their biological applications. Nanoparticles are now made using a variety of physico-chemical processes. In biological and medical applications where nanoparticle quality is critical, biogenic reduction of metal precursors to produce corresponding nanoparticles is less expensive, devoid of chemical contaminants, and environmentally benign. Green nanoparticles of various sizes, shapes, and chemical compositions have been produced today using a variety of methods, and their potential uses in a number of cutting-edge technical domains have been studied (Karim et al., 2023). Long before the word "nanotechnology" was created, physicist Richard Feynman presented a talk at an American university titled "There's Plenty of Room at the Bottom" on December 29, 1959. Nanotechnology has long been a popular subject in the scientific and technical domains. Nanotechnology is currently becoming more and more popular and creating a lot of conversation as technology advances at an ever-increasing rate. The focus of the scientific and technical area of nanotechnology is on creating and utilizing systems, technologies, and structures that deal with atoms and molecules at the Nano scale, or having one or more dimensions of less than 100 nanometers (100 millionth of a millimeter) (Adeyemi et al., 2022). Materials can display peculiar physical, chemical, and biological properties at the Nano scale. These properties may differ significantly from those of bulk materials and individual molecules or atoms. The bulk properties of materials are often significantly altered by the addition of Nano components. Remarkably, when utilized to create composite materials, metal or ceramic nanoparticles can become far stronger than what is anticipated by existing materials science models (Acharya et al., 2018). Because biological systems may readily absorb nanoparticles, concerns have been raised concerning the potential effects of nanotechnology on humans. The use of nanomaterial typically results in the production of new, environmentally harmful byproducts. Through eco-Nano toxicity research, the effects of nanomaterial on the world and all of its living things are currently being examined (Khan et al., 2017). The phrase "green nanotechnology" describes technology that lessens risks to the environment and human health. Create technology

that is clean. It has to do with the application of manufacturing processes and products based on nanotechnology. Green nanotechnology encourages the replacement of existing Nano products with new ones (Yadav et al., 2015). The term "green Nano biotechnology" describes the biological processes—such as those involving bacteria, plants, viruses, or their byproducts—that produce nanoparticles or nanomaterial. In addition to other biotechnological tools, like proteins and lipids. Numerous green nanoparticles have been produced recently utilizing a variety of methods, and their uses have been studied in a number of cutting-edge technical domains. These particles' shapes, sizes, and chemical composition are all clearly determined (Ahmed et al., 2018). Green nanotechnology should be promoted as a viable substitute for synthetic nanotechnology in order to address environmental concerns. This is in line with the principles of green science, which include reducing energy consumption, producing as little waste and pollution as possible, and developing products and nanomaterial that do not pose a threat to the environment or public health. Solid-state reactions, energy conservation, modifying the structure of nanomaterial to lessen their toxicity, recycling and reusability considerations, and substituting water for hazardous organic solvents are some of the nanotechnology techniques and approaches that are needed for these methods (Kharissova et al., 2019). The following categories can be used to broadly classify materials based on their variety:

This group includes carbon nanotubes (CNTs), graphemes, carbon quantum dots (CQDs), and another carbon-based nanomaterial.

(1) Examples of metallic nanomaterial include metal nanoparticles, metal oxide nanoparticles, bimetallic, trimetallic, and others.

(2) The constituents of ceramic-based nanomaterial are usually metal oxides, carbides, phosphates, and carbonates.

(3) A polymeric nanomaterial is considered natural, biosynthetic, or chemosynthesis if at least one of its dimensions falls between 1 and 1000 nm.

(4) Biomolecule-derived nanomaterial is made from proteins, lipids, polysaccharides, nucleic acids, and other biomolecules (Barhoum et al., 2014).

Based on their structure, most materials are divided into zero-, one-, two-, and three-dimensional categories; however, certain materials are in the middle. Nano materials are also categorized according to a wide range of additional factors, including their size and shape, their origin (biogenic,

atmospheric eugenic, or anthropogenic), and their use in business or research (Rashid, 2024). Op-down and bottom-up approaches are the two methods used to create nanomaterial. Bulk materials are divided into Nano scale structures using top-down methods. Mechanical ball milling, arc discharge, wire explosion lithography, laser ablation, and other top-down techniques are typical examples. Atoms, molecules, or even smaller units are used as building blocks in bottom-up methods to produce nanostructures (Aryal et al., 2019). Chemical reduction, sole-gel synthesis, photochemical synthesis, hydrothermal or solvothermal synthesis, chemical vapor deposition, co-precipitation, biological processes, etc. are examples of bottom-up methods. Stabilizing agents, reducing agents, and metallic precursors are the basic elements of the chemical process (both inorganic and organic). The tollens reagent from the polyol process, sodium citrate, acerbate, sodium borohydride (NaBH_4), elemental hydrogen, N, N-dimethyl form amide (DMF), and poly (ethylene glycol)-block copolymers are some of the reducing agents that are employed (Yoo et al., 2022).

Applications for nanomaterial could include drug delivery, biological labeling, environmental cleanup, chemical sensing and imaging, information storage, electronic and photonics and catalysis (Han et al., 2023). Recent decades have seen the development of intelligent and multifunctional nanoparticles in medicine and pharmaceuticals, particularly in the diagnosis and treatment of cancer, nanostructured electrodes in batteries, antimicrobial materials in the food, clothing, and cosmetics industries, and single-walled carbon nanotubes in communication technology devices (Malik et al., 2023). Despite the fact that synthetic nanomaterial have many uses and advantages today, historically, their manufacture and use were expensive and occasionally produced byproducts that were harmful to the environment. Because of its hazards and unfavorable effects, synthetic nanostructures are not widely used in medicine. Therefore, in an effort to reduce these unwanted effects, scientists are now developing nanomaterial in ecologically friendly ways. In actuality, green nanotechnology is the use of nanotechnology to environmentally friendly processes, reducing costs and possible environmental problems brought on by adverse externalities (Kumah et al., 2023).

Classification of Nanomaterial: Nano materials in the Nano scale range are separated into:

Zero-dimensional materials: All of these substances are larger than 100 nanometers; one of these is quantum dots, which have recently been used in the manufacturing of solar cells and transistors (Abdel Maksoud et al., 2022).

One-dimensional materials: These materials, which include nanotubes and Nano threads, will be essential in the manufacturing of electronics since they only have one dimension greater than 100 nanometers. These days, they are also utilized in food packaging to prevent contamination and spoilage, as well as in surface coatings that protect metal products from rust and corrosion (Mohammed et al., 2024).

Two-dimensional materials: These materials include, for example, materials having two dimensions more than 100 nanometers and Nano layers, which are used in the manufacturing of sensors (Mohammed et al., 2024).

Three-dimensional materials: These materials are categorized as Nanomaterial because they contain additional materials that are zero, one-dimensional, or two-dimensional, giving them certain attributes of the Nano range, or because they have dimensions larger than 100 nanometers or a Nano crystalline structure. Nano materials include metal powders, ultra-fine ceramic materials, and nanoparticles. It is noteworthy that this category of three-dimensional Nano material leads the globe in nanomaterial production overall due to its many technical uses (Mohammed et al., 2024).

Nanotechnology applications in the energy sector: Nanotechnologies have the potential to significantly enhance both conventional energy sources (fossil and nuclear fuels) and renewable energy sources (geothermal, solar, wind, water, tidal, or biomass) (Joudeh and Linke, 2022). For example, corrosion-resistant Nano-coated drilling probes lower expenses by increasing the longevity and productivity of machinery used to extract natural gas, oil, or geothermal resources. Other examples are very durable nanomaterial for lighter and stiffer rotor blades for wind and tidal power plants, and corrosion protection coatings for mechanically stressed components (bearings, gearboxes, etc.) (Hussein, 2023). Nanotechnologies will be particularly crucial for photovoltaic systems, which heavily rely on solar energy, as was previously indicated. For example, using anti-reflective coatings to increase light output may improve efficiency in conventional crystalline silicon solar cells. In addition to being essential for the use of clean energy sources like wind and geothermal,

nanotechnology's use in the energy industry would reduce reliance on traditional energy sources and increase use of alternative, greener sources like solar cells (Lina et al., 2022).

Nanotechnology also facilitates the complete and effective utilization of hydrogen energy (by employing innovative nanostructures that are characterized by their remarkable appetite in absorbing and storing hydrogen gas). In addition to reducing energy consumption, nanotechnology has created small photovoltaic solar panels that may be installed on facades and rooftops in place of solid glass facades. These panels work as efficient solar cells. This fosters the integration of solar cell energy generation with the building facade in order to achieve energy efficiency while keeping the desired design of the building, unlike ordinary solar cells that require a fixed placement. These films are made from rolls of flexible neoplastic (Rojas-Garcia et al., 2022).

Applying Energy Coating: Similar to how plants collect sunlight and use it to create chemical energy for growth, energy coating converts internal and external light into electrical energy. In order to generate a Nano energy coating that can absorb energy from both indoor and outdoor light sources, a titanium dioxide (TiO₂) pigment is injected. This light energy is converted to electrical energy after going through titanium dioxide and several electrodes Nano energy polymers, which are inexpensive, lightweight, flexible, and multifunctional, are created and produced using the main component of energy coating (Zhang et al., 2021). As seen above, the following are some benefits of using Nano lighting in the building envelope to support green architecture:

Supporting the reduction of energy consumption:

Nano sensor applications: The incorporation of Nano sensors into building materials, which enable the gathering of data and information from the local environment as well as its users, is one of the most important applications of nanotechnology. The building becomes a network of intelligent, interactive components that collect data on temperature, humidity, stress levels, and a variety of other measurable characteristics because they can even communicate with the user and other sensors (Soleymani et al., 2024). This information is essential for improving and monitoring the building's performance and for determining ways to lower internal energy consumption. For example: The building's environment control systems may recognize the user and adjust the temperature

accordingly. Similar to this, windows have the ability to automatically control passive communication between the sensors, which can be used to measure anything from the temperature of the surrounding air to the color of the walls, including the amount of sunlight that they reflect or let in (Shikha et al., 2022). Switch2Save promises significant energy savings in southern regions and other areas with high temperatures by lowering or eliminating the demand for air conditioners. "The cooling and heating energy demands of modern buildings can be reduced by up to 70 percent in warm regions of Europe. The devices could also be employed here as anti-glare protection against direct sunlight, albeit the savings are not as great in colder, northern climates. The maximum flexibility is theoretically provided by a composite window that combines thermo chromic and electro chromic layers. This allows developers and architects to offer customized solutions for a range of locations and structures. "We are currently putting the technology in an office building in Uppsala, Sweden, as well as the pediatric clinic of the second-largest hospital in Greece, located in Athens. For a full year prior to and following the installation of the new windows, energy usage in both buildings will be tracked and compared. By doing this, we can show how well the Switch2Save technology works in real-world situations and keep testing and improving it for various temperature zones (Shikha et al., 2022).

Nano sensors are used in air pollution monitoring because they use very little energy to monitor and identify harmful chemicals and air pollutants. Among the most popular types are:

Carbon nanotube sensors: The use of carbon nanotubes in the construction of these sensors and sensing apparatuses boosts their effectiveness. The external surfaces of the carbon tubes can also be covered with sheets of different polymers to identify the type of pollutants present (Shikha et al., 2022).

Solid-state Nano sensors: Nano sensors, which are linked to wireless devices via GIS (Geographic Information System) in buildings, are the ideal sensors for monitoring air pollution. This portable gadget with integrated Nano sensors enables real-time air pollution monitoring by pairing with a personal computer (PDA) via Bluetooth and GPS (Global Positioning System). It's also expected that cars will be able to manage the interior environment of homes using sensors created with nanotechnology and their own intelligence. These sensors will communicate with the other devices and equipment to clean the air, control the temperature

of the water and areas, measure the humidity levels within the house, determine how much lighting is required, and track the changes in the seasons and the hours of day and night throughout the year. It is also expected that sensors will be developed to monitor vibration, corrosion, and other problems in structures (Krzysztof et al., 2022).

Green Nanotechnology: The combination of green architecture and nanotechnology is known as "Nano architecture," which is another term for the integration of green architecture with Nanotechnology. Since its products and applications in buildings provide architectural solutions to a range of environmental concerns created by structures and boost building efficiency throughout their life cycle, nanotechnology is a sophisticated application of green architecture (Tohlob and Morsi, 2024). As seen in the graphic, some instances of nanotechnology applications that adhere to the principles of green building are as follows:

1. Self-cleaning window glass that changes color according on the amount of light required (photochromic).
2. Fireproof and odor-absorbing wall paints.
3. For facades, cement with Nano-additives is utilized.
4. Solar-powered Nano cells that generate power.
5. Window glass that cleans itself and is photochromic—that is, changes color according on the quantity of light required—paints for walls that are both fireproof and odor-absorbing.
6. Cement is used in facades that contain Nano-additives.
7. Integrated Nano cells that generate solar energy (Soleymani et al. 2024).

Green Nanotechnology: Given that biological systems may easily absorb nanoparticles, questions have been raised regarding the possible impacts of nanotechnology on people. Usually, the usage of nanomaterial produces new, environmentally harmful byproducts. Eco-Nano toxicity study is now being conducted to determine the effects of nanomaterial on the planet and its entire living species. "Green nanotechnology" is defined as the technology used to create clean technologies in order to lessen risks to the environment and human health. It has to do with the use of nanotechnology-based products and production techniques. In order to create new Nano products, green nanotechnology promotes the replacement of current ones. The creation of innovative Nano products has enhanced the surroundings (Manoj et al., 2023). Green Nano

biotechnology is the technique of manufacturing nanoparticles or nanomaterial utilizing various biotechnological instruments and biological processes, such as those involving bacteria, plants, viruses, or their byproducts, including proteins and lipids. Today, several green nanoparticles have been created using a range of techniques, and their possible applications in several cutting-edge technical fields have been investigated. These particles' sizes, shapes, and chemical makeup are all well described (Vijayaram et al., 2024). Also, it is crucial to adhere to the principles of green science, which include creating nanomaterial and products with the least amount of energy, waste, and pollution, as well as without endangering the environment or human health, in order to address environmental concerns and establish green nanotechnology as a competitive alternative to synthetic nanotechnology. To achieve this, nanotechnology techniques and methods—such as solid-state reactions, water substitutes for dangerous organic solvents, energy conservation, altering the structure of nanomaterial to reduce their toxicity, and considering recycling and reusability are crucial (Osman et al. ,2024). Furthermore, the main goal of producing nanomaterial from green sources is to employ natural resources to solve environmental issues. or instance, environmentally beneficial magnetite nanoparticles (NPs) are used to remove arsenic from water and scavenge dangerous chlorinated organic solvents from the environment. The use of nanomaterial to create sensors for contaminants like lead or coliform bacteria will enhance the simplicity of analysis and detection limits in comparison to existing analytical techniques (Khan et al., 2024).

Green Synthesis of Nanoparticles: Green synthesis techniques have the potential to lower the toxicity of nanoparticles, which makes them highly appealing. As a result, using vitamins, amino acids, microbes, and plant extracts is becoming popular nowadays. The unique traits of the best organisms or their extracts, such as their metabolic pathways, phytochemical contents, enzyme activities, cell development circumstances, and optimal response, must be taken into account. The three basic phases in the synthesis of nanoparticles utilizing a biological system include selecting a solvent medium, a safe and ecologically acceptable reducing agent, and a nontoxic substance to employ as a capping agent to stabilize the generated nanoparticles (Somda et al., 2024).

Nanoparticle characterization: Compared to macroscopic materials, nanomaterial has a large surface-area-to-volume ratio that is orders of magnitude different. Temperature, solvent conditions during synthesis, reactant amounts, salt, and surfactant additions are some of the variables that affect the size and structure of nanomaterial. The development of repeatable nanomaterial manufacturing has been shown to depend on nanomaterial characterization. The study of composition, structure, and additional attributes like physical, chemical, electrical, and magnetic characteristics is known as characterization. Numerous methods exist for characterizing nanomaterial, but each one has some degree of uncertainty. The size and form of NPs in aqueous suspension were determined using UV-Vis spectra. NPs with sizes ranging from 2 to 100 nm are commonly described by wavelengths between 300 and 800 nm. TEM and SEM are typically used to describe the size and shape of NPs. The size, phase, and translational symmetry of metallic nanoparticles can all be ascertained using XRD. To determine the structure, the diffraction pattern that results from X-rays entering a nanomaterial is compared to standards. FTIR spectroscopy is used to identify the types of metabolites or functional groups that are present on the surface of NPs and may be in charge of stabilizing and reducing NPs. The DLS and EDAX are used to examine the size distribution dispersed in liquid and the elemental components of NPs, respectively (Ranjan et al., 2023).

Conclusions

- 1- Compared to traditional methods, biological production of nanoparticles offers several advantages and shows a lot of potential.
- 2- Gold (Au) and silver (Ag) nanoparticles is the subject of much investigation due to their importance in disinfection studies.
- 3- The production of various metal and metal oxide nanoparticles (such as Fe, Pd, Ru, PbS, Mn, CdS, CuO, CeO₂, TiO₂, and ZnO) is crucial for environmental and health applications.
- 4- Researchers are looking closely into the potential uses of nanoparticles in environmental science, medicine, and agriculture.
- 5- Most small-scale tests on nanoparticle applications have been conducted in research labs. It is necessary to produce green building materials and nanomaterial, including Nano cells, Nano fillers, Nano coatings, and Nano insulation. Sustainability should be given top priority in product creation while minimizing costs.

Recommendations

1. Eco-Friendly Production of Nanoparticles for Use in Medicine, Research Focus: Examine environmentally friendly, natural resources such as plant extracts, algae, and fungi to create nanoparticles through green synthesis techniques. Concentrate on creating nanoparticles that can be applied to wound healing, cancer treatment, and medication delivery systems. The Significance of It: An environmentally friendly substitute for conventional nanoparticle manufacturing techniques, which frequently call for hazardous ingredients, is green chemistry. In biomedical fields, this can improve nanoparticles' efficacy and biocompatibility.
2. Owners of both public and private structures are under pressure to utilize more environmentally friendly materials because of regulations and guidelines that require engineers to use eco-friendly materials in buildings. The need for nanotechnology to create sustainable green architecture is growing as a result of this.
3. Educational seminars and info graphics—a quick, easy, and inexpensive way to create and share information—can help raise awareness of the significance of nanotechnology in a variety of domains by converting complex data, ideas, and concepts into visually appealing, captivating, and easily understood pictures and drawings that convey a lot of information about a story, news, or subject in a straightforward, uncomplicated manner.
4. Because of its numerous uses, it is crucial to improve the recycling of waste from electronic boards by incorporating some significant chemicals, like Nano copper oxide, and employing environmentally friendly materials.
5. Establishing rules for the shift to smart cities that will encourage investment and creativity by improving the use of digital technology in many facets of people's life.
6. Encouraging scientific endeavors and research institutions to invest in nanotechnology research outputs by providing the necessary infrastructure and support, enabling them to be inventive and creative in the realm of technology and integration.
7. By eliminating contaminants from the air, nanotechnology is also utilized to safeguard the environment. By removing harmful gasses from the environment, it protects humans from breathing in dangerous contaminants. By employing micro-sensors, nanotechnology has been utilized to identify contaminants at the molecular level.

References

- Abdel Maksoud MIA, Fahim RA, Bedir AG, Osman AI, Abouelela MM, El-Sayyad GS, Elkodous MA, Mahmoud AS, Rabee MM, AaH A-M, Rooney DW. (2022). Engineered magnetic oxides nanoparticles as efficient sorbents for wastewater remediation: a review. *Environ Chem Lett* 20(1):519–562. <https://doi.org/10.1007/s10311-021-01351-3>
- Acharya, R., et al. (2018). "Nanoparticles in the environment: sources, behaviour and toxicity." *Journal of Environmental Science and Health, Part A*, 53(11), 1175-1209.
- Adeyemi JO, Oriola AO, Onwudiwe DC, Oyedeji AO. (2022). Plant extracts mediated metal-based nanoparticles: synthesis and biological applications. *Biomolecules* 12(5):627. <https://doi.org/10.3390/biom12050627>
- Ahmed, A.; Hamzah, H.; Maaroo, M. (2018). Analyzing formation of silver nanoparticles from the filamentous fungus *Fusarium oxysporum* and their antimicrobial activity. *Turk. J. Biol.*, 42 (1) (2018): pp. 54-62.
- Aryal S, Park H, Leary JF, Key J. (2019). Top-down fabrication-based nano/microparticles for molecular imaging and drug delivery. *Int J Nanomedicine*. (2019) Aug 19; 14:6631-6644. doi: 10.2147/IJN.S212037. PMID: 31695361; PMCID: PMC6707381.
- Barhoum A, Rahier H, Abou-Zaied RE, Rehan M, Dufour T, Hill G, Durfrense A. (2014). Effect of cationic and anionic surfactants on the application of calcium carbonate nanoparticles in paper coating. *ACS Appl Mater Interfaces* 6(4):2734–2744.
- Han, Daguang, Haidar Hosamo, Chunli Ying, and Ruimin Nie. (2023). "A Comprehensive Review and Analysis of Nanosensors for Structural Health Monitoring in Bridge Maintenance: Innovations, Challenges, and Future Perspectives" *Applied Sciences* 13, no. 20: 11149. <https://doi.org/10.3390/app132011149>
- Hussein, H.S. (2023). The state of the art of nanomaterials and its applications in energy saving. *Bull Natl Res Cent* 47, 7 (2023). <https://doi.org/10.1186/s42269-023-00984-4>
- Joudeh, N., Linke, D. (2022). Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists. *J Nanobiotechnol* 20, 262 (2022). <https://doi.org/10.1186/s12951-022-01477-8>
- Karim N, Liu S, Rashwan AK, Xie J, Mo J, Osman AI, Rooney DW, Chen W. (2023). Green synthesis of nanolipo-fibersomes using Nutriose® FB 06 for delphinidin-3-O-sambubioside delivery: characterization, physicochemical properties, and application. *Int J Biol Macromol* 247:125839. <https://doi.org/10.1016/j.ijbiomac.2023.125839>
- Khan I, Saeed K, Khan I. (2017). Nanoparticles: properties, applications and toxicities. *Arab J Chem*. 2017; 12(7):908–31.
- Khan, M.Q., Khan, J., Alvi, M.A.H. et al. (2024). Nanomaterial-based sensors for microbe detection: a review. *Discover Nano* 19, 120 (2024). <https://doi.org/10.1186/s11671-024-04065-x>.
- Kharissova OV, Kharisov BI, Oliva González CM, Méndez YP, López I. (2019). Greener synthesis of chemical compounds and materials. *R Soc Open Sci*. 2019 Nov 6; 6(11):191378. doi: 10.1098/rsos.191378. PMID: 31827868; PMCID: PMC6894553.
- Krzysztof Grabowski, Shreyas Srivatsa, Aniruddh Vashisth, Leon Mishnaevsky, Tadeusz Uhl. (2022). Recent advances in MXene-based sensors for Structural Health Monitoring applications: A review, *Measurement*, Volume 189, 2022, 110575, ISSN 0263-2241, <https://doi.org/10.1016/j.measurement.2021.110575>.
- Kumah, E.A., Fopa, R.D., Harati, S. et al. (2023). Human and environmental impacts of nanoparticles: a scoping review of the current literature. *BMC Public Health* 23, 1059 (2023). <https://doi.org/10.1186/s12889-023-15958-4>
- Lina Wang, Mavd P.R. Teles, Ahmad Arabkoohsar, Haoshui Yu, Kamal A.R. Ismail, Omid Mahian, Somchai Wongwises, (2022). A holistic and state-of-the-art review of nanotechnology in solar cells, *Sustainable Energy Technologies and Assessments*, Volume 54, 2022, 102864, ISSN 2213-1388, <https://doi.org/10.1016/j.seta.2022.102864>.
- Malik S, Muhammad K, Waheed Y. (2023). Emerging Applications of Nanotechnology in Healthcare and Medicine. *Molecules*. 2023 Sep 14; 28(18):6624. doi: 10.3390/molecules28186624. PMID: 37764400; PMCID: PMC10536529.
- Manoj K., Rakesh R., Sinha M. P. and Raipat B. S. (2023). Different techniques utilized for characterization of metallic nanoparticles synthesized using biological agents: A review. *Balneo and PRM Research Journal*, 14(1): 534.

- Mohammed Saleh, Afroz Gul, Abir Nasir, et al. (2024). Comprehensive review of Carbon-based nanostructures. *J Ind Eng Chem.* 2024. <https://doi.org/10.1016/j.jiec.2024.11.052>.
- Osman, A.I., Zhang, Y., Farghali, M. et al. (2024). Synthesis of green nanoparticles for various applications: A review. *Environ Chem Lett* 22, 841–887 (2024). <https://doi.org/10.1007/s10311-023-01682-3>.
- Rashid R. (2024). What will it take to open South Korean research to the world? *Nature.* 2024 Aug; 632(8026):S2-S5. doi: 10.1038/d41586-024-02685-y. PMID: 39169255.
- Ranjan R., Manoj K., Manoranjan P.S. (2023). XRD analysis of nanoparticles synthesized using aqueous and alcoholic extracts of "Cuscuta reflexa". *Balneo and PRM Research Journal*, 14(3): 585.
- Rojas-Garcia, E., Castañeda-Ramírez, A.A. , Angeles-Beltrán, D. , López-Medina, R., Maubert-Franco A.M., . (2022). Enhancing in the hydrogen storage by SWCNT/HKUST-1 composites: Effect of SWCNT amount, *Catalysis Today*, Volumes 394–396, 2022, Pages 357-364, ISSN 0920-5861, <https://doi.org/10.1016/j.cattod.2021.08.004>.
- Shikha Gulati, Harish Neela Lingam B, et al. (2022). Improving air quality with Functionalized Carbon Nanotubes. *Chemosphere*, 299, 134468. <https://doi.org/10.1016/j.chemosphere.2022.134468>.
- Soleymani, M., Amrollahi, R., Taghdir, S. et al. (2024). Nanotechnology for thermal comfort and energy efficiency in education. *Sci Rep* 14, 21502 (2024). <https://doi.org/10.1038/s41598-024-72853-7>.
- Tohlob, A.A.H., Morsi, H.E.ED. (2024). Nanotechnology's impact on sustainable architecture. *J Umm Al-Qura Univ Eng.Archit.* 15, 138–161 (2024). <https://doi.org/10.1007/s43995-024-00048-2>.
- Vijayaram S, Razafindralambo H, et al. (2024). Applications of Green Synthesized Metal Nanoparticles. *Biol Trace Elem Res.* 2024 Jan; 202(1):360-386.
- Somda, D., Bargul, J.L., Wesonga, J.M. et al. (2024). Green synthesis of Brassica carinata microgreen silver nanoparticles, characterization, safety assessment, and antimicrobial activities. *Sci Rep* 14, 29273 (2024). <https://doi.org/10.1038/s41598-024-80528-6>.
- Vijayaram S, Razafindralambo H, Sun YZ, Vasantharaj S, Ghafarifarsani H, Hoseinifar SH, Raeeszadeh M. (2024). Applications of Green Synthesized Metal Nanoparticles - a Review. *Biol Trace Elem Res.* 2024 Jan; 202(1):360-386. doi: 10.1007/s12011-023-03645-9. Epub 2023 Apr 13. PMID: 37046039; PMCID: PMC10097525.
- Yadav A, Kon K, Kratosova G, Duran N, Ingle AP, Rai M. (2015). Fungi as an efficient mycosystem for the synthesis of metal nanoparticles: progress and key aspects of research. *Biotechnol Lett.* 2015 Nov; 37(11):2099-120. doi: 10.1007/s10529-015-1901-6. Epub 2015 Jul 12. PMID: 26164702.
- Yoo, S., Nam, D.H., Singh, T.I. et al. (2022). Effect of reducing agents on the synthesis of anisotropic gold nanoparticles. *Nano Convergence* 9, 5 (2022). <https://doi.org/10.1186/s40580-021-00296-1>.
- Zhang, W., Hu, K., Tu, J., Aierken, A., Xu, D., Song, G., et al. (2021). Broadband Graded Refractive index TiO2/Al2O3/MgF2 Multilayer Antireflection Coating for High Efficiency Multi-junction Solar Cell. *Solar Energy* 217, 271–279. doi:10.1016/j.solener.2021.01.012.