Sustainable Materials and Technology

Imran Uddin *Editor*

Sustainable Nanomaterials

Synthesis and Environmental Applications

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Imran Uddin
Editor

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Editor
Imran Uddin
Nanolab, Environmental Mineralogy
Research Group
Research Institute of Biomolecular
and Chemical Engineering
University of Pannonia
Veszprém, Hungary

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Foreword

In the new millennium, sustainability has become the greatest challenge humanity is facing. The steadily increasing human population, together with rapidly expanding global consumption, accompanied with adverse environmental impacts such as global climate change and pollution, are placing great stress on depleting natural resources and the global ecosystem. At the same time, humankind has maneuvered itself into a painstakingly deep addiction to the continuous availability of cheap energy supplied by fossil fuels. The end of this era is well within eyesight for various reasons, so viable alternatives have to be quickly developed. Given that the flow of (the Sun's) energy being received by the Earth is virtually unlimited, but its forms are not directly suitable for meeting the needs of modern civilization, transformation (and storage) of energy is needed that requires vast amounts of specific materials. Unfortunately, material resources (such as ores of technological metals or other chemical elements) are even more limited than fossil reserves, and they are to be quickly depleted by the anticipated technological revolution in the coming decades focusing on avoiding the worst consequences of global climate change. Fortunately, however, impressive recent developments in nanotechnology have opened new horizons for providing technological solutions to many problems without the excessive use of valuable material resources. I am pretty sure that there are other revolutionary solutions in the field of nanotechnology that can alleviate our ever-increasing hunger for energy and bulk materials. In a truly sustainable world nanotechnology must play a leading role in providing the needs of modern societies without massively depleting our limited material resources. However, as always, there are drawbacks and emerging concerns with the use of nanotechnology, such as increasing energy consumption in manufacturing or adverse effects on human health, just to name a few. As a cautionary tale we can recall how brilliant plastics looked at the onset of their widespread use, and today the world is literally drowning into the ocean of plastic waste debris without the hope of getting rid of them any time soon. To avoid a similarly bleak future with nanomaterials, technological innovations in nanotechnology should go hand in hand with cutting-edge research focusing on their a-priori environmental impacts of their foreseen mass applications in order to avoid falling into traps like modern societies did several times throughout the last century. This book offers prime examples for both approaches, i.e., technological innovations as well as studying the potential environmental impacts of nanomaterials (ironically, the latter also frequently uses tools that are based on nanotechnology). Although at first glance the combination of two buzzwords in the title of the book seems a bit kitschy ('sustainable nanomaterials'), nature provides perfect examples of truly sustainable nanomaterials: in fact, all forms of life are based on that. We may even conclude that in the modern world, anything genuinely sustainable must somehow be linked to nanomaterials or technologies. The 'bulk era' of the modern civilization (i.e., mass-scale depletion of non-renewable material resources) is quickly coming to the end, and the only 'salvation' might be using nanomaterials that are more effective and require less critical materials by several orders of magnitude. This book presents examples of applications of intelligent nanomaterials for a wide variety of industries ranging from energy production through agriculture to the IT sector, as well as for pollution mitigation such as wastewater treatment and remediation. Other chapters focus on health-related issues of the use of nanomaterials, such as using them as antibacterial agents or drug-delivery vehicles, or assessing their human toxicity. The content of the book is finely balanced between these different aspects, testifying that the word 'sustainable' is not just a fancy buzzword in its title, but rather a strong commitment to introduce these promising technologies responsibly for the co-benefit of humankind and nature. I wish the readers of this book to be impressed by its colorful complexity inspiring new ideas in this emerging field of science.

Prof. András Gelencsér
Professor, Rector
Atmospheric Chemist
Member of the Hungarian Academy
of Sciences
University of Pannonia
Veszprém, Hungary

Preface

We are immensely pleased to present our book, Sustainable nanomaterials: Synthesis and environmental applications. Verily, as scholars and tutors in the study and pedagogy of nanotechnology, we often had difficulties in identifying a comprehensive reference book that effectively encapsulates essential subject matter within the area, while providing enough depth for novice researchers.

Therefore, we took it upon ourselves to fill this gap in the literature by meticulously compiling this book, which aims to serve as a valuable resource for both students and experienced researchers in the field of nanomaterials. Our main objective was to create a comprehensive guide that not only covers the synthesis techniques of sustainable nanomaterials but also highlights their diverse environmental applications. We believe that this book will be instrumental in advancing the understanding and utilization of sustainable nanomaterials in various industries and scientific disciplines.

This book offers a comprehensive exploration of several subjects within the discipline, providing in-depth analysis while avoiding oversimplification or excessive focus on a single area of study. Moreover, this book not only covers the foundational concepts and theories but also delves into the practical applications of these subjects. It presents real-world examples and case studies to illustrate the relevance and importance of the theories discussed. Furthermore, it includes the latest advancements and breakthroughs in the field, making it a valuable resource for both beginners and experts seeking a comprehensive understanding of the discipline.

The book covers a wide range of topics, including the synthesis and characterization of sustainable nanomaterials, their various applications in different fields such as environment, and healthcare, as well as the potential risks and challenges associated with their use. It provides a comprehensive overview of the current state of research in the field, highlighting the latest advancements and future prospects. Additionally, the book includes case studies and practical examples to illustrate the real-world applications of sustainable nanomaterials, making it a valuable resource for both academics and industry professionals.

A sufficient number of topics are included on the sustainable synthesis and fabrication of nanomaterials and various aspects of emerging and existing applications, including clean energy and environmental sustainability, wastewater treatment, dye degradation, sustainable bioremediation, sustainable agriculture, food processing, and packaging. In order to understand the ecotoxicological effects, topics like sustainable nanomaterials used as antimicrobial agents and drug delivery have been included. This book includes chapters on sustainable nanomaterials in textile industries and machine learning.

The proposed content of the book in its present form makes it a complete reference resource suitable for researchers in the subject, with a particular emphasis on its relevance to senior graduate, M.Tech., and MS students specializing in nanotechnology. The book would furthermore function as an essential reference for researchers in many domains of materials science seeking to make contributions to the realm of sustainable nanomaterials. With its comprehensive coverage of the subject, the book offers a wealth of knowledge for those interested in understanding the principles and applications of sustainable nanomaterials. It not only caters to the needs of researchers in nanotechnology but also provides valuable insights for professionals in various fields of materials science. Its emphasis on sustainability highlights the growing importance of eco-friendly materials in today's world, making it an invaluable resource for anyone seeking to make a positive impact in the field of nanomaterials.

Imran Uddin
Senior Research Scientist
Nanolab
Environmental Mineralogy Research
Group
Research Institute of Biomolecular
and Chemical Engineering
University of Pannonia
Veszprém, Hungary

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Finally, I would like to express our heartfelt gratitude to the family members who assumed additional obligations during the compilation of this book. The consistent support and comprehension shown by our peers enabled us to allocate several hours toward the completion of this book.

Contents

Editor and Contributors

About the Editor

Imran Uddin has a Ph.D. in biotechnology from the National Chemical Laboratory, Pune, India. His research interest lies in the fabrication of biocompatible nanostructures for nanobiosensors and flexible electronics. Moreover, he is also working on developing new industrially relevant renewable nanomaterials. He completed his postdoctoral fellowships at Rhodes University, South Africa, and Korea University, Seoul, Republic of Korea. He has served as an assistant professor of biotechnology at INC, AMU, Aligarh. He is the recipient of a number of awards and fellowships, including CSIR Pool Scientists, Start-up Research Grant (DST Young Scientists), CSIR SRF, and ICAR NET. Currently, he is a senior research scientist at the Nanolab, Environmental Mineralogy Research Group, Research Institute of Biomolecular and Chemical Engineering, University of Pannonia, Veszprém, Hungary.

Contributors

Mostafa M. Abdul Faculty of Science, Cairo University, Giza, Egypt

O. A. Abiodun Department of Home Economics and Food Science, Faculty of Agriculture, University of Ilorin, Ilorin, Nigeria

O. T. Ajewole Department of Plant Science and Biotechnology, Federal University Oye-Ekiti, Ekiti, Nigeria

O. A. Akinlolu Food Security and Safety Focus Area, Faculty of Natural and Agricultural Sciences, North-West University, Mmabatho, South Africa

A. O. Akintayo Department of Home Economics and Food Science, Faculty of Agriculture, University of Ilorin, Ilorin, Nigeria;
School of Agriculture, Food and Wine, The University of Adelaide, Urrbrae, Australia

Mohammad Arshad Department of General Studies and Science, Alfayha College, Aljubail, Saudi Arabia

Shashi Bala Department of Chemistry, University of Lucknow, Lucknow, Uttar Pradesh, India

T. T. Bello Department of Agricultural Science Education, Federal College of Education, Abeokuta, Nigeria

Chandra S. Bhatt Department of Biological Sciences, SRM University-AP, Andhra Pradesh, India

O. A. David Department of Plant Science and Biotechnology, Federal University Oye-Ekiti, Ekiti, Nigeria

Ahmed M. El-Khawaga Faculty of Medicine, Department of Basic Medical Sciences, Galala University, Galala City, Suez, Egypt

Abdelaziz Omar Elshiekh Faculty of Science, Cairo University, Giza, Egypt

O. A. Fabiyi Department of Crop Protection, Faculty of Agriculture, University of Ilorin, Ilorin, Nigeria

Oluwatoyin Adenike Fabiyi Department of Crop Protection, Faculty of Agriculture, University of Ilorin, Ilorin, Nigeria

Faisal Forooque Department of Biochemistry, Faculty of Life Sciences, Aligarh Muslim University, Aligarh, India

Hamid Faculty of Science, Cairo University, Giza, Egypt

Abdullah M. Heikal Faculty of Science, Cairo University, Giza, Egypt

Ottó Horváth Research Group of Environmental and Inorganic Photochemistry, Center for Natural Sciences, Faculty of Engineering, University of Pannonia, Veszprém, Hungary

Sabeeha Jabeen Department of Chemistry, University of Lucknow, Lucknow, Uttar Pradesh, India;
Department of Chemistry, Integral University, Lucknow, Uttar Pradesh, India

Adhish Jaiswal Department of Chemistry, University of Lucknow, Lucknow, Uttar Pradesh, India

Balázs Kakasi University of Pannonia, Research Institute of Biomolecular and Chemical Engineering, Veszprém, Hungary

Hamdy Ahmed Kamal Faculty of Science, Cairo University, Giza, Egypt

Parshant Kaushik Division of Agricultural Chemicals, ICAR-Indian Agricultural Research Institute, New Delhi, India

Kashif Ullah Khan Doctoral School of Material Science and Technology, Obuda University, Budapest, Hungary

Mohd Sajid Khan Department of Biochemistry, Faculty of Life Sciences, Aligarh Muslim University, Aligarh, India

Mohd Shoeb Khan Faculty of Engineering and Technology, Department of Applied Sciences and Humanities, Jamia Millia Islamia, New Delhi, India

Tahmeena Khan Department of Chemistry, Integral University, Lucknow, Uttar Pradesh, India

Arvind Kumar Department of Botany, B.R. Ambedkar Bihar University, Muzaffarpur, Bihar, India

Abdelaziz M. Mohamed Faculty of Science, Cairo University, Giza, Egypt

Riham R. Mohamed Faculty of Science, Cairo University, Giza, Egypt

Mohammed Mudabbiruddin Doctoral School of Material Science and Technology, Obuda University, Budapest, Hungary

Mohd Muaz Mughees Department of Biochemistry, Faculty of Life Sciences, Aligarh Muslim University, Aligarh, India

Shoaib Mukhtar Research Group of Environmental and Inorganic Photochemistry, Center for Natural Sciences, Faculty of Engineering, University of Pannonia, Veszprém, Hungary

Szabolcs Tamás Nagy Hungarian University of Agriculture and Life Sciences, Georgikon Campus, Keszthely, Hungary

Safikur Rahman Department of Botany, B.R. Ambedkar Bihar University, Muzaffarpur, Bihar, India

Saman Rais Department of Chemistry, Aligarh Muslim University, Aligarh, India

Saman Raza Department of Chemistry, Isabella Thoburn College, Lucknow, U.P., India

Priya Saini Division of Agricultural Chemicals, ICAR-Indian Agricultural Research Institute, New Delhi, India

Shumaila Shahid Division of Plant Pathology, ICAR-Indian Agricultural Research Institute, New Delhi, India

Erzsébet Szabó-Bárdos Research Group of Environmental and Inorganic Photochemistry, Center for Natural Sciences, Faculty of Engineering, University of Pannonia, Veszprém, Hungary

Atirah Tauseef Section of Plant Pathology and Nematology, Botany Department, Aligarh Muslim University, Aligarh, India

Imran Uddin Nanolab, Research Institute of Biomolecular and Chemical Engineering, University of Pannonia, Veszprém, Hungary

Flóra Judit Varga University of Pannonia, Research Institute of Biomolecular and Chemical Engineering, Veszprém, Hungary

Mohd Wasi Department of Botany, Faculty of Life Sciences, Aligarh Muslim University, Aligarh, India

Ibrahim Garba Wawata Department of Science, Faculty of Science and Technology, Kampala International University Western Campus, Kampala, Uganda;
Department of Pure and Applied Chemistry, Kebbi State University of Science and Technology Aliero, Aliero, Nigeria

Green Nanotechnology for Clean Energy and Environmental Sustainability

Sabeeha Jabeen, Tahmeena Khan, Adhish Jaiswal, and Shashi Bala

Abstract Green nanotechnology has emerged as a promising project that aims to integrate nanotechnology principles with environmental sustainability and emerged as a promising alternative for clean energy. In this chapter, the role of green nanotechnology in overcoming the challenges of clean energy provision and environmental sustainability has been discussed. The chapter critically examines and highlights the potential environmental impacts associated with the use of nanomaterials (NPs) and covers different aspects of green nanotechnology in energy production such as solar cells, fuel cells, and electronic devices. The findings suggest that green nanotechnology has great potential to solve energy crises, and may be further explored. The applications of green nanotechnology in the pursuit of environmental sustainability and the role of nanomaterials as catalysts in environmental remediation processes to remove pollutants from the air and water have also been included. The green fabricated nanomaterials can break down pollutants into harmless products or facilitate their removal by adsorption. Nanotechnology-based sensors are also used to monitor the environment in real time and help detect and reduce pollution. The adoption of green nanotechnology is effective in reducing energy consumption, increasing resource efficiency, and reducing environmental impact. Regulatory and responsible design processes are essential to protect human health and the environment throughout the lifecycle of nanotechnology products.

Keywords Green nanotechnology · Clean energy · Environmental sustainability · Wastewater remediation · Solar energy

S. Jabeen · A. Jaiswal · S. Bala (✉)
Department of Chemistry, University of Lucknow, Lucknow, Uttar Pradesh 226007, India
e-mail: shashi_bala@lkouniv.ac.in

S. Jabeen · T. Khan
Department of Chemistry, Integral University, Lucknow, Uttar Pradesh 226026, India

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1 Introduction

As the world grapples with the challenges of climate change and environmental degradation, the need for clean energy and sustainable practices is greater than ever [1]. In this context, green nanotechnology has emerged as a promising solution. This chapter evaluates green nanotechnology and its potential applications in the production of clean energy resources for environmental sustainability [2–4]. Green nanotechnology is a rapidly growing field that aims to create sustainable solutions for clean energy provision by exploiting the unique properties of nanoparticles (NPs). Nanoparticles are materials with sizes in the nanometre range, suitable for different applications [5–7]. Green nanotechnology can also be used to treat environmental pollution by removing pollutants from air, water, and soil by using NPs as adsorbents or catalysts [1]. One of the main applications of green nanotechnology is in solar cells, where NPs are used to increase the efficiency and cost-effectiveness of solar power generation. The chapter discusses the use of NPs, such as TiO_2, ZnO, and quantum dots, in solar cells that can improve light absorption and charging, thereby making energy conversion efficient. Another application of green nanotechnology is in fuel cells, where NPs can be used as catalysts to increase the efficiency and durability of fuel cells [8, 9]. The chapter also explores the use of NPs of platinum (Pt), palladium (Pd), and ruthenium (Rh) in fuel cells can improve the catalytic performance and stability of fuel cell electrodes, extending energy conversion, electricity, and life of fuel cells along with the potential use of green nanotechnology in batteries where NPs can be used to improve the energy density, charge capacity, and cycle stability of batteries [10–12]. The use of NPs such as nitrocellulose, carbon nanotubes, and graphene is also discussed which are used to create stronger, energy-efficient, and renewable materials, thereby reducing environmental pollution [13]. Despite the potential use of green nanotechnology in clean energy and environmental protection, there are still issues that need to be resolved. One of the most important issues is the potential environmental and health problems associated with NPs which can be toxic to organisms and the environment, if not handled properly. Therefore, developing a safe and sustainable way to produce, use, and dispose of NPs is important.

2 Green Nanotechnology

Green Nanotechnology is a field of study that uses nanotechnology principles to design and manufacture environmentally friendly materials and products [14]. It is based on the principles of green chemistry and aims to reduce or eliminate the use and production of harmful substances in the chemical process as depicted in Fig. 1. Green nanotechnology is based on the use of NPs, nanotubes, and other nanostructures like that of CuO, Fe_2O_3, $LaFe_2O_3$, $LaMnO_3$, and $CuFe_2O_4$, etc. NPs have unique physical and chemical properties with high surface area/volume ratios, due to their different properties, making them suitable for many applications in different

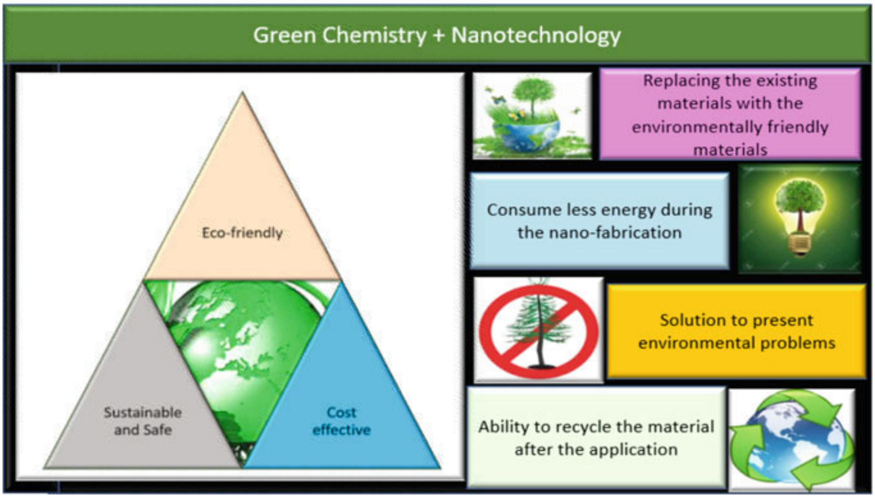

Fig. 1 Benefits of green nanotechnology

fields and improving functionality and catalytic activity [15, 16]. Although green nanotechnology offers solutions for clean energy and environmental sustainability, some materials used for green and clean energy are much more expensive Therefore, it is important to create effective solutions that maximize environmental and financial benefits.

3 Application of Green Nanotechnology for Clean Energy and Environmental Sustainability

In recent years, the use of nanotechnology has increased in energy and environmental sustainability [17]. As depicted in Fig. 2. It can provide a solution to some major environmental problems.

3.1 Green Nanotechnology Applications for Clean Energy

The production and use of electricity are important sources of environmental pollution, and the search for cleaner and sustainable electricity is an important issue [18]. Figure 3. depicts some applications of green nanotechnology for clean energy production.

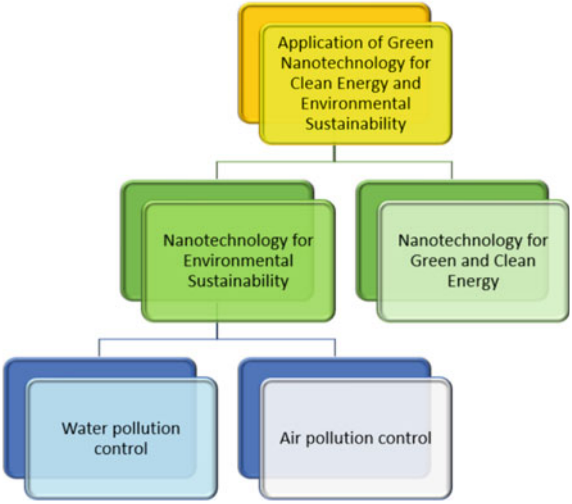

Fig. 2 Applications of green nanotechnology for environmental sustainability

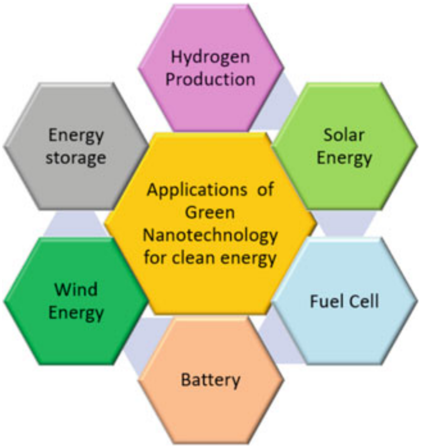

Fig. 3 Green nanotechnology applications for clean energy

3.1.1 Green Nanotechnology for Solar Energy

Solar energy is one of the most promising renewable energy sources. Solar Cell is a device that converts sunlight into electricity. Solar panels are made of silicon material, which has limitations such as high cost and poor performance. Green nanotechnology offers a solution to these limitations by using NPs, nanowires, and other nanostructures to improve the performance of solar cells**.** The development of efficient and low-cost solar energy is essential for the widespread use of solar energy. Green nanotechnology is used to increase efficiency and reduce the cost of solar cells. NPs are used to improve the absorption of light in sunlight. The use of nanoscale semiconductor quantum dots shows promise in improving the performance of solar cells. Additionally, using TiO_2 NPs the solar cells can reduce manufacturing costs as depicted in Fig. 4a–b [19, 20]. In addition, nanotechnology allows the fabrication of ultra-thin and flexible solar cells, allowing them to be integrated into a variety of surfaces including windows, walls, and even clothing. Modern solar power generation methods include the use of toxic materials and energy-efficient techniques. However, nanotechnology has enabled the development of environmentally friendly production. For example, researchers have developed a low-cost, cost-effective solution to create nanoscale solar cells using non-toxic materials such as organic polymers and perovskite compounds [21, 22]. The combination of nanotechnology and energy storage technology provides a sustainable and continuous source of clean energy. Green nanotechnology not only improves solar power generation and storage but also contributes to the sustainability of all energy sources. Nanomaterials can improve the efficiency of energy transmission and distribution by reducing energy during transport. In addition, nanotechnology-based sensors and monitoring devices monitor power generation, energy consumption, and grid performance in real time, making it easier to manage grid power and efficiency.

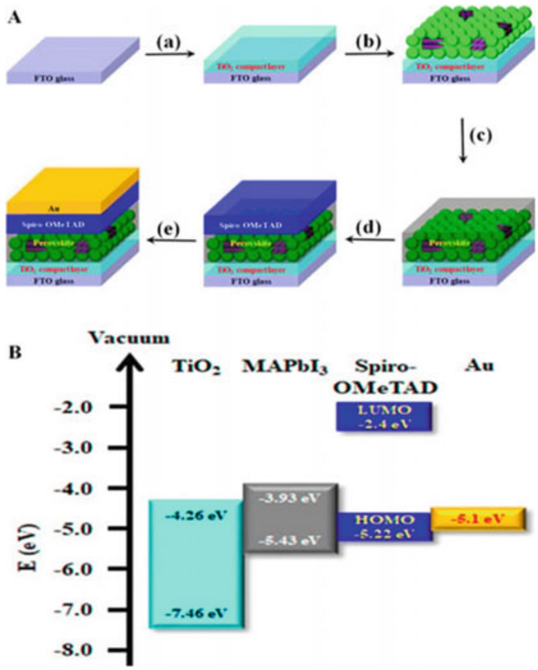

Fig. 4 **a** Schematic illustration of fabrication processes of perovskite solar cells with TiO_2 films, including TiO_2 NPs and flakes of TiO_2 nanotubes, and **b** an energy band diagram of the device. Image Credit [19]

3.1.2 Green Nanotechnology for Fuel Cell

Green nanotechnology has emerged as a promising field with the potential to revolutionize energy production and storage. One of the areas of interest in green nanotechnology is the development of fuel cells. A fuel cell is an electrical device that converts the electrical energy of a fuel such as hydrogen into electrical energy. They offer a cleaner, more efficient alternative to traditional energy sources, making them an essential part of the transition to a sustainable energy future [23]. Green nanotechnology plays an important role in improving the performance and sustainability of fuel cells. With their unique properties and high surface area, nanomaterials can improve the performance of fuel cells. For example, Pt NPs have been widely investigated and used as catalysts in fuel cells due to their excellent electrocatalytic activity. By reducing the size of the particles to the nanoscale, their surface area increases, which enhances the performance of the fuel cell by providing more space for the electrochemical reaction [24]. In addition, green nanotechnology enables the development of many other inexpensive and environmentally friendly catalyst materials. Scientists have investigated the use of metallic NPs of iron (Fe), nickel (Ni), and cobalt (Co) as nanocatalysts in fuel cells. These materials can provide similar or better catalytic performance. This not only reduces the cost of producing fuel cells but also reduces the environmental impact associated with the mining and refining of precious metals. Additionally, nanostructured membranes are designed to improve ion transport in fuel cell electrolytes. Made from materials such as carbon nanotubes or graphene, these membranes have excellent electrical properties, energy efficiency, and selectivity, which reduce electrical resistance and ensure the optimum operation of the fuel cell. Nanotechnology-based approaches can be used to develop efficient ways to produce and store hydrogen, a clean and rich fuel [25, 26]. As shown in Fig. 5. Nanomaterials can be used in photocatalytic systems that use solar energy to split water molecules into hydrogen and oxygen. Additionally, nanoscale materials can improve hydrogen capacity, resulting in safer and more efficient transportation of hydrogen [27]. Overall, the integration of green nanotechnology into fuel cells holds great promise for a cleaner future.

3.1.3 Green Nanotechnology for Battery

Nanomaterials play an important role in battery development. By manipulating materials at the nanoscale, researchers have improved battery energy storage, cycle stability, and charge/discharge efficiency [28]. For example, SiO_2 NPs and graphene-based materials have been explored to replace graphite anodes in lithium-ion batteries. These nanomaterials are capable of storing more lithium ions, which could help in the development of stronger and longer-lasting batteries. In addition, green nanotechnology enables the use of more environmentally friendly materials in battery components [29]. For example, the use of nanocellulose derived from renewable resources such as plant fibres as a sustainable and biodegradable material for battery electrodes has been explored. Nanocellulose has excellent properties,

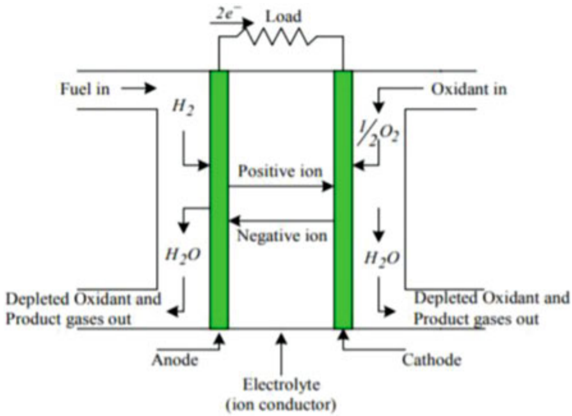

Fig. 5 Schematic illustration of fuel cell operational diagram [26]

high surface area, and good electrical properties, making it promising for new green batteries. Additionally, green nanotechnology can help improve battery manufacturing processes. By combining nanoscale materials and techniques such as solution or electrospinning, battery electrodes with improved porosity, uniformity, and controlled nanostructure can be fabricated [30], which improves the ion and electrical charge in the battery, resulting in more electricity, faster charging, and longer life. Also, green nanotechnology could lead to the development of safer and more durable batteries. Nanomaterials can improve the stability and performance of non-toxic, abundant, and environmentally friendly products such as sodium-ion or zinc-ion batteries which have the potential to replace lithium-ion lithium-ion batteries, reducing reliability on rare and expensive materials and reducing the environmental impact associated with their removal and disposal. Additionally, nanotechnology could help develop self-healing batteries. By using nanomaterials, batteries can be improved in terms of energy storage capacity, cycle stability, and manufacturing process, the integration of environmental information and the development of safe and self-healing batteries can reduce the environmental impact associated with the manufacture and use of the fuel lamp [31].

3.1.4 Green Nanotechnology for Wind Energy

Wind energy is another promising renewable energy source. Using nanotechnology in the production of wind turbines can increase efficiency and reduce environmental impact [32]. Nanocoatings can be applied to wind turbines to improve their aerodynamic performance. This increases the efficiency of wind turbines and reduces the energy required to generate electricity. In addition, the use of nanoscale materials in the construction of wind turbines can reduce their weight, thereby reducing transportation and installation costs [33]. In addition, wind turbines often have to operate in harsh environments that are eroded by cold, hot, sand, and seawater [34]. In addition to the beam area of the main load-bearing structure, it is very important

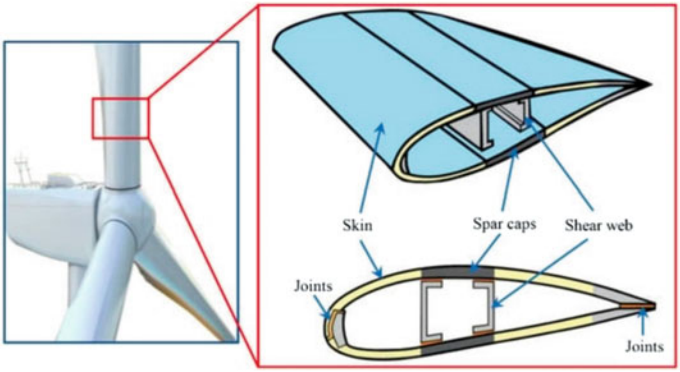

Fig. 6 Structural drawing of wind turbine blade Image Credit [36]

to use carbon fibre nanocomposites in non-bearing or other load-bearing structures [35, 36]. For example, the German Aerodyn Energiesysteme Gmbh company uses carbon fibre nanomaterials in the root of the turbine blade to improve the fracture strength and behaviour of the root material and to reduce the dynamic load applied to the bolts as depicted in Fig. 6.

3.1.5 Green Nanotechnology for Energy Storage

Energy storage plays an important role in integrating renewable energy into the grid, as it helps reduce the interdependence and variability of renewable energy generation. Green nanotechnology offers new ideas to improve energy storage technology, improve their performance, and reduce their environmental impact [37]. One of the areas where green nanotechnology has made a significant contribution is the development of high-performance batteries. Nanomaterials have unique properties and large surface areas that can be used to improve energy storage, cycle stability, and charge/discharge of batteries [38]. In addition, green nanotechnology plays an important role in the creation of supercapacitors. Supercapacitors have fast-charging and fast-charging capabilities but always have lower power compared to batteries. However, nanomaterials such as carbon nanotubes (CNT) or GO nanomaterials can be used to improve the energy storage of supercapacitors [39]. These nanomaterials provide a large surface area and facilitate rapid absorption and desorption of ions, leading to improved energy storage performance as shown in Fig. 7. Green nanotechnology can also contribute to the development of other electronic products such as fuel cells and hydrogen storage systems. Nanomaterials can be used to strengthen catalysts, improve ion transport membranes, and increase hydrogen capacity. Additionally, nanostructured materials such as metal hydrides or carbon-based nanomaterials offer the opportunity to shrink and recover hydrogen by enabling the use of hydrogen as clean energy. Energy storage systems can be improved in terms of capacity, cycle stability, and charge/discharge rates [40–44].

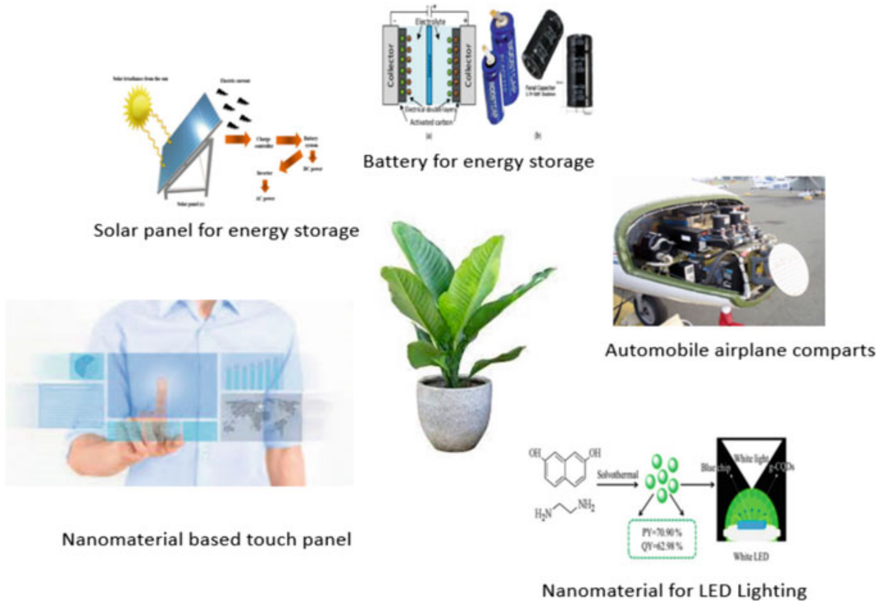

Fig. 7 Green synthesized nanomaterials in energy storage devices. Image Credit [41–44]

3.1.6 Green Nanotechnology for Hydrogen Production

Green nanotechnology is a promising method to increase hydrogen production and contribute to the development of clean energy in the future. Hydrogen is a versatile clean fuel that can be used for a variety of applications, including transportation and power generation. Green nanotechnology offers new ways to improve hydrogen production processes, increase efficiency, and reduce environmental impact [45]. One area where green nanotechnology shows great potential is in photocatalytic systems for water separation. Water separation is a process that uses renewable energy sources such as sunlight to split water molecules into hydrogen and oxygen as shown in Fig. 8. Nanomaterials such as TiNPs or nanocomposites can be used as excellent photocatalysts to drive this reaction. The special properties of nanomaterials such as high surface area, tuneable band gap, and good insulation can improve hydrogen production by improving light absorption and conversion [46]. Scientists are exploring the use of nanoscale metals, metal oxides, and other nanocatalysts for efficient and sustainable hydrogen production. These nanocatalysts can improve reaction kinetics, increase active sites, and reduce energy requirements, resulting in higher hydrogen production and lower costs. In addition, green nanotechnology plays an important role in the development of hydrogen storage and transport. Nanomaterials can be used to increase hydrogen storage capacity and safety. For example, researchers are

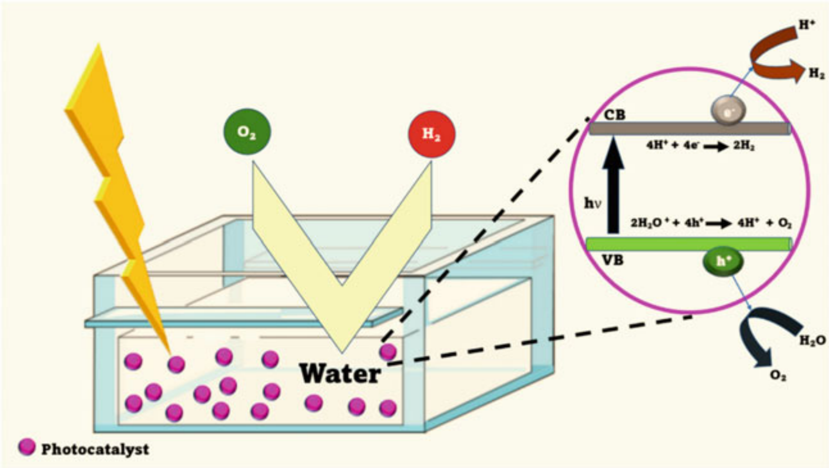

Fig. 8 A schematic of how hydrogenase catalyst can be used reversibly to produce hydrogen, and ‘burn’ it in a fuel cell. Image credit [49]

exploring the use of nanostructured materials such as metal hydrides, CNT, or metal–organic frameworks to adsorb and store high-density hydrogen [47]. Nanomaterial-based storage systems offer advantages such as compactness, reversibility, and rapid release of hydrogen gas when needed. In addition, green nanotechnology contributes to the development of efficient and selective hydrogen production. Nanoscale materials such as graphene or zeolites can be used to create membranes that selectively allow hydrogen to pass through while blocking other gases [48]. These membranes are capable of purifying and separating hydrogen from many feedstocks, including petroleum or biomass-derived gas, facilitating the incorporation of hydrogen into products. Finally, green nanotechnology has the potential to increase the level of hydrogen production and overcome the problems associated with clean and versatile energy [49].

3.2 Applications of Green Nanotechnology in Environmental Sustainability

Green nanotechnology also has great potential in the field of environmental sustainability [50]. Some of the applications are depicted in Fig. 9.

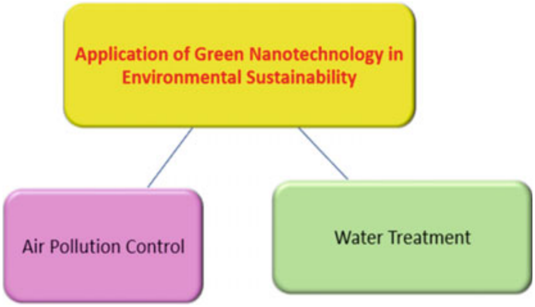

Fig. 9 Green nanotechnology applications for environmental sustainability

3.2.1 Green Nanotechnology in Water Treatment

Green nanotechnology holds great promise in water treatment. Using nanomaterials in filtration, adsorption, and disinfection can remove pollutants and contaminants from water, thus providing clean and safe water for many purposes. Green nanotechnology can be used in many water treatment applications such as filtration, adsorption, and disinfection. Nanomaterials such as carbon nanotubes, graphene, Metal oxide nanostructures (ZnO, CuO, TiO_2, ZnO/CuO nanocomposite, and nanocellulose are being explored to develop efficient and effective technologies [50]. One of the most promising green nanotechnologies in water treatment is the use of nanomaterials for water filtration. Nanofiltration membranes can remove bacteria, viruses, heavy metals, organic substances, etc. They can remove various pollutants from water [51].

Benefits of Green Nanotechnology in Water Treatment

Nanomaterials can remove pollutants and contaminants from water sources, thus providing clean and safe water for many purposes [52]. In addition, the use of nanomaterials in water treatment can reduce the use of chemicals and energy, thereby saving costs and reducing environmental impact and there are various methods to remove pollutants such as photocatalysis, nanofiltration, and nano absorption as depicted in Fig. 10. According to the World Health Organization, 844 million people worldwide suffer from a shortage of clean water [53]. Poor water quality is the most common cause of disease in developing countries due to inadequate water treatment practices [54]. Therefore, the main directions of current research are water recycling and wastewater treatment [55]. Over the years, new nanomaterials for bioremediation have been discovered, including metal oxide, zinc oxide, graphene nanoplatelets, chitosan, nanoscale zeolites, and carbon nanotubes. Calcium alginate, modified dendrimers, multi-walled carbon nanotubes, and other organic nanomaterials are used for toluene hydrogenation, phenol degradation, crude oil degradation, metal removal, etc. In addition to organic nanomaterials, inorganic NPs of uranium, inorganic nitrate, polychlorinated, and TiO_2 NPs are also used [56]. Among the

Fig. 10 Benefits of green nanotechnology in water treatment [7]

various types of metal oxide/metallic NPs, magnetic NPs have received much attention due to their ability to treat large volumes of wastewater by magnetic separation [7, 57]. It has been reported that metal oxide NPs have been biosynthesized from *Moringa oleifera* seed waste and can be used to recover and release metal ions from wastewater. They showed enhanced removal of chlorpyrifos which was higher as compared to the standard [58].

3.2.2 Air Pollution Control

Air contamination is one of the world's most critical issues, and its definition is based on the change set in the natural atmospheric composition that is provoked by introducing different pollutants sources (chemical, biological, or physical) resulting from human activity or industrial processes, such as carbon monoxide (CO), chlorofluorocarbons (CFC), heavy metals (As, Cr, Pb, Cd, Hg), hydrocarbons, nitrogen oxides, organic chemicals (VOCs, and dioxins), SO_2, sand particles, and biological substances. The ecosystem (e.g., vegetation and living organisms) as well as human health is affected by poor air quality causing different types of fatal diseases, for example, cancer, respiratory, and cardiovascular diseases [59–61]. Air pollution is one of the biggest problems in the world and can be defined as a change in the natural composition of air for anthropogenic, geological, or toxic reasons. Bad weather can affect ecosystems (including plants and living organisms) and human health, leading to many deadly diseases such as cancer, respiratory disease, and heart disease. The World Health Organization (WHO) reported in 2014 that approximately 7 million people died from air pollution in 2012[62, 63]. Air pollution are two types (1) outdoor air pollution and (2) indoor air pollution.

Outdoor Air Pollution

The most important problem of outdoor air is global warming, which causes many changes in air, soil, and water around the world. Greenhouse gases (GHGs) are believed to contribute directly to global warming. The main greenhouse gases are carbon dioxide (CO), methane (CH_4), nitrous oxide (NO_2), and fluorinated gases. The growth of human activities leads to the problem of greenhouse gas emissions. Because most greenhouse gases stay in the atmosphere for hundreds of years, they can have long-term effects on the climate [64]. Various control and treatment technologies have been developed to eliminate and monitor gas emissions and their risks to humans and the environment. Nanotechnology is a powerful medical tool that can control and treat air pollution in many ways, using the properties of nanomaterials and using them as adsorbents, catalysts, membranes, and sensors [65]. Adsorption of nanomaterials is proving to be a more efficient and cost-effective process due to the availability and regenerative capabilities of nanomaterials as well as the high surface area that can increase the effective mobility of nanomaterials. Solid sorbents for CO_2 capture are divided into three groups: (1) hot sorbents (>400 °C), (2) medium temperature sorbents (200–400 °C), and (3) non-hot sorbents added with alkali metals (Li, Na, K, Cs, Fr) treated nanoparticles exhibit the ability to capture carbon dioxide at low temperatures, such as potassium titanate (K–Ti–NT) and sodium titanate (Na–Ti NT) have been used to capture CO_2 at low temperatures (below 200 °C) [66, 67]. Functionalized carbon nanotubes (CNTs) have been successfully used to capture CO_2 and improve the performance of moisture, which reduces adsorption capacity due to competition for adsorption sites between water molecules and CO_2 [68]. As another example of nanotechnology's role in greenhouse gas production, many catalytic processes are dedicated to the conversion or decomposition of methane (CH_4) and nitrous oxide (NOx). For example, metallic nickel (Ni) NPs and Iron (Fe) NPs have been used as catalysts for the thermal decomposition of methane to produce hydrogen [69], while TiO_2 coated with stainless steel mesh has been successfully used for the photocatalytic degradation of (CH_4) [70]. On the other hand, Molybdenum-doped titanate nanotubes (Mo-TNTs) and their derivatives have been widely reported for the photocatalytic oxidation of CO_2 and NO_2 [71]. The In_2O_3 gas sensor has many detection methods for ethanol concentration, as shown in Fig. 11 [72]. Many studies have been carried out to obtain the best parameters affecting the degradation rate and air pollutant removal efficiency. Silver deposited on the TiO_2 surface reduces the electron–hole recombination rate and controls environmental pollution [73]. Apart from greenhouse gases, one of the emissions associated with different environmental problems and very dangerous for human health is sulphur dioxide (SO_2) [74]. Nanomaterials have been used to eliminate SO_2 emissions for SO_2 oxidation in the environment. Removal of SO_2 sometimes causes some changes

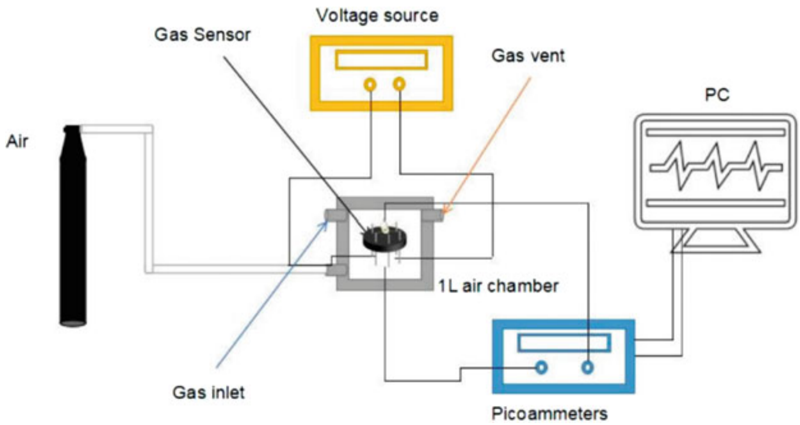

Fig. 11 In_2O_3 gas sensor for detection of ethanol concentration [72]

in the morphology or properties of the material. It has also been shown that the SO_2 adsorption process leads to significant changes in magnetic properties when magnetic nanoparticles (MNPs) are used. For example, the adsorption of SO_2 on the surface of $COFe_2O_4$ MNPs results in about a 20% reduction in their saturation and permanent magnetization and a 9% reduction in coercive force [75, 76].

Indoor Air Pollution

Indoor air pollution has recently emerged as a major concern as it directly affects human health. Among household pollutants, organic allergens cause childhood asthma, atopic hypersensitivity, and other symptoms such as headache, nausea, rhinitis, pharyngitis, emphysema, and lung cancer. Therefore, it is necessary to develop an effective method to control and eliminate the emission of Volatile organic contaminants (VOCs) [77]. The most common carbonyl compound in the air is formaldehyde (HCHO), a precursor to the production of hard materials such as phenolic and urea–formaldehyde resins, which are widely used in wood products and insulation materials. Many methods are used for formaldehyde removal, including decomposition using photocatalysts and physical adsorption on porous materials, and chemisorption, which is considered a good method without re-emissions due to strong chemicals. However, HCHO has serious problems with its removal [78]. For example, energy-efficient processes using photocatalysts are not suitable for indoor removal of HCHO due to the need for UV exposure and the risk of generating harmful ozone [79]. In addition, hydrocarbons can produce carcinogenic products through secondary chemical reactions. Therefore, many attempts have been made to improve formaldehyde removal and researchers developed polyacrylonitrile (PAN)-based carbon nanofiber (CNF) membranes with tailored microporosity and rich nitrogen-containing functional groups as excellent adsorption surfaces. A large amount of formaldehyde was adsorbed on the pore surface of PAN-activated carbon nanofibers (ACNFs), even at low concentrations. However, air humidity