RECENT APPLICATIONS OF WASTE DERIVED INNOVATIVE MATERIALS IN HEALTHCARE AND ENVIRONMENTAL SUSTAINABILITY

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10.53478/TUBA.978-625-6110-22-9.ch07

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Abstract

Waste-derived innovative materials are the one of the recent topics that have gained importance today in terms of contributing to sustainability. The development and use of such materials in many areas such as health, environment, food, etc. offers new alternatives to traditional methods available today. Research in this area not only addresses the current pressing problems of waste management, but also unlocks new possibilities for developing cost-effective and environmentally friendly solutions that can adapt to the needs of many different fields. The current studies on the use of waste-derived innovative materials in health fields such as drug delivery, tissue engineering, biosensing as well as in environmental fields such as the remediation of wastewater, soil pollution and air pollution are overviewed in this chapter. The advantages, limitations, possible solutions and the future of such materials are also discussed furtherly.

Keywords

Waste-derived innovative materials, sustainability, healthcare applications, environmental applications

Introduction

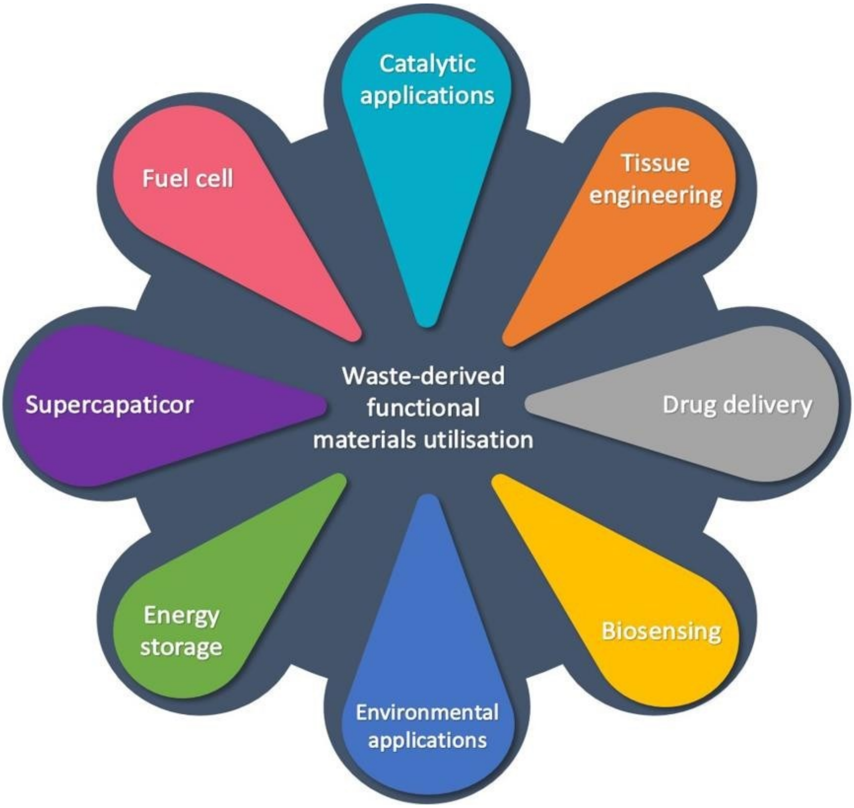
The increasing consumption of both durable and nondurable consumer goods, accompanied by the consequent generation of waste materials, is raising concerns among the global population. This has prompted a sense of urgency for the adoption of more efficient measures in environmental protection (Ikram et al., 2023). In recent years, generating functional materials from waste using effective strategies has become more prominent. The principle of "waste-to-value" holds substantial economic and environmental importance. In this regard, significant emphasis has been placed on utilizing natural and renewable materials to create cost-effective and environmental friendly adsorbents for water pollution remediation (Soffian et al., 2022).

Waste materials originate from various sources, including commercial, construction, household, industrial, institutional, imported, and public goods or products. One practical approach to categorizing waste materials is based on their environmental impact levels. Bertram et al. (Bertram et al., 2018) classified wastes into four categories: (i) eco-friendly, (ii) biodegradable, (iii) non-biodegradable, and (iv) toxic wastes.

Recently, the increased global concerns about the sustainability of the Earth have raised public and industrial awareness regarding the harmful impacts of chemical toxins and non-biodegradable materials. The accumulation of waste materials is a growing problem, posing threats not only to the environment but also to public safety. Addressing this issue involves recycling and utilizing these waste materials in industries instead of disposing of them. Consequently, there is a rising demand for the efficient transformation of wastes into benign materials, aiming to minimize the amount of waste released into the environment.

The utilization of waste-derived materials in various fields including energy storage, supercapacitor, fuel cell, catalytic applications, tissue engineering, drug delivery, biosensing, and environmental analysis is possible (see Figure 1) In this chapter, numerous waste-derived materials and their applications in the field of health care and environmental management are introduced and discussed in detail.

Figure 1.
Utilization of waste-derived materials in different fields.



Recent Applications of Waste Materials

Healthcare Applications

In today's world, where sustainability and environmental responsibility hold significant importance, the healthcare industry is actively adopting innovative strategies to minimize its impact on the environment. An interesting approach gaining attraction involves the use of innovative materials derived from waste materials in various healthcare applications. This shift not only tackles the pressing issue of waste management but also unlocks new possibilities for developing cost-effective and eco-friendly solutions that can adapt to the dynamic needs of healthcare. These materials, once considered discarded remnants, are now finding purpose in advancing healthcare technologies and practices. From by-products to recycled plastics and electronic waste, these materials are smartly repurposed to meet the demanding requirements of the healthcare sector. This sustainable approach not only reduces environmental impact but also aligns with the principles of a circular economy, where waste transforms into a valuable resource. Beyond environmental consciousness, the exploration of waste-derived materials within healthcare signifies a convergence of management and cutting-edge medical innovations. It demonstrates the potential to revolutionize how the industry sources and produces materials (Y. C. E. Li, 2019). This section reviews the applications of waste-derived materials, shedding light on how these seemingly ordinary sources are actively shaping a greener and more sustainable future for healthcare. Different types of new innovative materials derived from different types of wastes, possess characteristics that can be effectively utilized in applications in healthcare field. These materials are frequently used in many different healthcare fields such as bioimaging, drug delivery, biosensing, tissue engineering (Choi et al., 2014; Faikrua et al., 2009; George et al., 2019; Hu et al., 2015; L. Li et al., 2018; Y. Li et al., 2018, 2023; Mauney et al., 2011; Patel et al., 2021; Shan et al., 2019; Tseng et al., 2015; L. Wang et al., 2014; Zheng et al., 2022).

Drug delivery has critical importance in the healthcare industry as it plays a critical role in improving clinical outcomes and patient well-being. Efficient drug delivery maximizes the bioavailability of drugs, ensuring that therapeutic agents reach their targets in optimal doses and minimize side effects. Furthermore, new drug delivery technologies enable controlled delivery of drugs, enabling consistent use, which is crucial for chronic conditions. The continuous evolution of drug delivery strategies holds the promise of revolutionizing healthcare by maximizing therapeutic benefits while minimizing adverse effects (Y. C. E. Li, 2019; Pillai & Panchagnula, 2001; Prausnitz & Langer, 2008; Tibbitt et al., 2016). For these reasons, numerous studies are currently being conducted with waste-based materials for drug delivery (L. Li et al., 2018; Y. Li et al., 2018, 2023; Patel et al., 2021; Rudzinski et al., 2016). Polysaccharide-based materials are widely used because they are biocompatible and biodegradable. Since they have different functional groups in their structures, they can easily bind to biomolecules and release drugs through various mechanisms (Y. C. E. Li, 2019). Among these materials, chitosan, lignin, cellulose and their derivatives are frequently used. Chitosan, a natural polymer originating from chitin found in the exoskeletons of crustaceans like shrimp and crabs, as well as in fungal cell walls, has become a focus of interest in drug delivery applications. Biomass-based chitosan, derived from renewable biomass sources, offers an environmentally friendly alternative to traditional extraction methods. Its appeal lies in features like biocompatibility, biodegradability, low toxicity, and distinctive physicochemical properties (Dash et al., 2011; Zhang et al., 2010). This variant of chitosan can be skillfully crafted into diverse drug delivery vehicles, including nanoparticles, microparticles, and hydrogels (Ahsan et al., 2018; Jayakumar et al., 2010; Kravanja et al., 2019; Zhang et al., 2010). These vehicles serve to encapsulate and shield drugs, enabling their controlled release precisely at the target site (Ahsan et al., 2018; Ali & Ahmed, 2018; Bernkop-Schnürch & Dünnhaupt, 2012; Bhattarai et al., 2010; Nagpal et al., 2010). Patel et al. prepared a bioactive multifunctional chitosan/cellulose nanocrystal scaffold. An increase in the mechanical strength of the developed structure has been reported. It was also reported that the developed composite scaffold of chitosan/cellulose nanocrystal showed improved sustained drug release. In addition, it was also stated that the developed structure can be used not only in drug delivery but also in tissue engineering and as an antimicrobial agent (Patel et al., 2021). In another study, a biomass-based magnetic fluorescent nanoparticles were synthesized using magnetic core of Fe_3O_4 nanoparticles, fluorescent marker of carbon dots and chitosan. In the study, it was reported that the addition of the synthesized material effectively improved the drug loading capacity in 5-fluorouracil encapsulation and release experiments (L. Li et al., 2018).

Lignin, a complex and polymeric compound naturally occurring in the cell walls of plants, has emerged from its traditional role as a byproduct of the paper and pulp industry to capture attention for its versatile applications, particularly in biomedicine. Derived from biomass, especially wood and other plant materials, lignin is increasingly recognized for its potential in various fields. In the realm of drug delivery, lignin takes on a crucial role. It can be transformed into nanoparticles or microparticles, serving as effective carriers for pharmaceuticals (Alqahtani et al., 2019; Figueiredo et al., 2017; Garg et al., 2022; Kumar et al., 2021; Yiamsawas et al., 2017). These lignin-based particles present an opportunity for controlled release, enhancing the therapeutic effectiveness of drugs. Moreover, the adaptability of lignin-based materials allows for potential modifications to improve targeting capabilities, facilitating precise and efficient drug delivery to specific tissues or cells. The inherent properties of lignin, including its ability to form films and matrices, position it as a promising candidate for sustained release drug delivery systems, ensuring a prolonged and sustained therapeutic impact (Alqahtani et al., 2019; Figueiredo et al., 2017; Garg et al., 2022; Kumar et al., 2021;

Yiamsawas et al., 2017). Li et al. developed poly(ε-caprolactone) (PCL)-containing lignin-chitosan biomass-based nanocomposite porous scaffolds. It is reported that the scaffolds obtained exhibit interconnected and adjustable pore structures. In the study, scaffolds loaded with the anti-bacterial drug enrofloxacin were reported to show a slow drug release profile, adjustable release rate and favourable long-term anti-bacterial activity (Y. Li et al., 2023). In the study of Li et al. alkali lignin was first modified and then treated with sodium dodecyl benzenesulfonate. Controlled release of avermectin is demonstrated with the developed material (Y. Li et al., 2018).

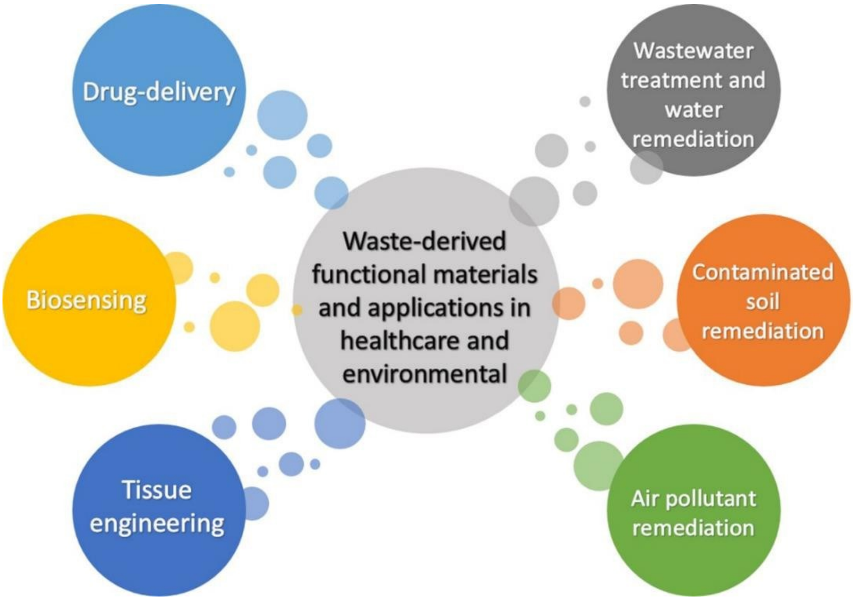
Cellulose, the most abundant biopolymer on Earth, is a natural polysaccharide found in plant cell walls. Biomass-based cellulose, derived from renewable sources like wood, cotton, or other plant materials, is gaining attention for its potential applications, owing to its abundance, biocompatibility, and biodegradability. This versatile cellulose variant can undergo processing to yield nanocellulose, encompassing cellulose nanocrystals (CNC) and cellulose nanofibers (CNF). These nanocellulose materials emerge as promising drug carriers, leveraging their high surface area, biocompatibility, and capacity to encapsulate and release pharmaceutical agents (Habibi, 2014; Klemm et al., 2011). Moreover, cellulose-based hydrogels offer another avenue, providing a platform for controlled drug release by efficiently absorbing and retaining water over time. This multifaceted approach underscores the significance of biomass-based cellulose in advancing drug delivery technologies (Chang & Zhang, 2011; Habibi, 2014; Zainal et al., 2021). In the study of George et al. biomass-based nanocomposite hydrogel was prepared and curcumin delivery was demonstrated. In the study, zinc oxide nanoparticles (ZnO NPs) phytosynthesised using musk melon (*Cucumis melo*) seed extract were placed in hydrogel matrices and crosslinking was performed using dialdehyde cellulose prepared from sugarcane (*Saccharum officinarum*) bagasse (SCB) (George et al., 2019).

These materials and their derivatives have many applications in the field of biosensing. Biosensors are small devices that enable selective analysis by specifically detecting the target analyte. The advantages of biosensors compared to traditional analysis methods are that they perform sensitive and selective analysis, reach low detection limits, are inexpensive and easy to use. Recently, there have been many studies on biosensor designs with innovative materials developed from waste-based materials in order to contribute to sustainability (Shan et al., 2019; L. Wang et al., 2014; Zheng et al., 2022). There are biosensor studies for the determination of biomarkers such as glucose, uric acid, determination of various heavy metals or determination of various physiological parameters. In the study by Wang et al, Kenaf stem based macroporous carbon material was synthesized and biosensor application was demonstrated (L. Wang et al., 2014). The electrocatalytic activity of the electrodes prepared with the synthesized material was investigated by cyclic voltammetry and amperometry techniques and it was stated that the material provides large surface area and accelerates mass and electron transfer. Glucose, amino acid and H_2O_2 determination was performed with the developed sensor. Zheng et al. synthesized phosphated lignin-based carbon nanofibers and developed a wearable biosensor using this material (Zheng et al., 2022). In the study, determination of uric acid in urine was carried out with the developed biosensor. Shan et al. developed a biosensor for glucose determination by enzymatic biosensing using biomass derived carbon material (Shan et al., 2019). In the study, the electrode surface was modified with carbon material derived from three-dimensional (3D) porous cane vine (wisteria) stalk and then glucose oxidase enzyme was immobilized on this surface. Electrochemical characterizations were performed with cyclic voltammetry and electrochemical impedance spectroscopy techniques. The developed biosensor was reported to have a wide linear range (0.58 μM to 16 mM) and low detection limit (0.19 μM).

Tissue engineering is this incredible field that brings together ideas from engineering, biology, and materials science, all with the aim of crafting functional biological tissues. The big mission here is to create artificial organs or tissues—ones that can step in to replace, repair, maintain, or even boost the function of tissues in the human body that have taken a hit from damage or disease. It's like a crossroads where science, technology, and health meet to open up possibilities for improving and restoring our bodies. Recently, in order to contribute to sustainability, studies have been carried out with innovative materials produced from waste materials in the field of tissue engineering (Choi et al., 2014; Faikrua et al., 2009; Hu et al., 2015; Mauney et al., 2011; Tseng et al., 2015). Choi et al. developed a crosslinkable chitosan derivative by modifying chitosan with various functional groups. As a result of the treatments, the degradation rate of chitosan hydrogel decreased, promoting the proliferation of encapsulated chondrocytes, ECM deposition and enhanced repair of damaged cartilage (Choi et al., 2014). There are also studies for the treatment of defects in the central nervous system or skin after modification of chitosan with various polymers (Faikrua et al., 2009; Tseng et al., 2015). Mauney and colleagues used silk to produce a bladder alternative. It was reported that the developed silk-based bladder alternative increased the bladder capacity and was resistant to stresses (Mauney et al., 2011). In another study, a structure to be used as a bone substitute was developed by preparing silk mixed material (Hu et al., 2015).

The scheme for the use of waste-derived materials in the field of healthcare and environmental is given in Figure 2.

Figure 2.
Utilization of waste-derived materials in healthcare and environmental



Application in Environmental Management

Wastewater Treatment and Water Remediation

According to the United States Environmental Protection Agency (EPA), the Basics of Water Remediation involve a series of actions by water utilities to restore normal service following a confirmed contamination incident. This incident is defined as the presence of chemical, biological, or radiological substances at concentrations significant enough to adversely affect public health or the environment. The remediation process, with a timeframe determined case-specifically, comprises three phases: Characterization, Decontamination, and Clearance. The characterization phase aims to understand the contamination extent, identifying contaminants, their interactions in water, and their concentrations. Information from strategic sampling guides protective measures, and a clearance goal is set based on defined risks. Public health and environmental risks are continually assessed. Decontamination phase involves choosing and implementing water treatment methods based on factors like effectiveness, resource availability, time, and cost. Infrastructure decontamination may be necessary, including cleaning or replacing contaminated surfaces. Proper management and disposal of contaminated wastes are integral to this phase. Lastly, clearance involves sampling and data review to assess if clearance goals have been met. Sampling is conducted using EPA-approved methods, ensuring compliance with regulations. If clearance is achieved, the water system can return to normal service, with the possibility of clearing specific areas while others undergo decontamination. Long-term monitoring may be necessary to confirm the remediation process's effectiveness after the system is restored to normal service (EPA, 2023).

The contamination of water resources is a highly contentious issue globally, given its potential for long-term or even lethal consequences for living things. Addressing water pollution is a significant challenge for both public health and a sustainable future. Currently, the rapid growth of industrialization and urbanization has resulted in significant water pollution, imposing considerable strain on both ecosystems and human health (Miklos et al., 2018). More than a third of the world's renewable freshwater resources are allocated for industrial, residential, and agricultural needs. Unfortunately, a significant portion of these activities leads to water pollution through the introduction of various geogenic and synthetic substances, such as dyes, pesticides, fertilizers, radionuclides, and heavy metals. Therefore, there is an immediate need to employ efficient methods for elimination of harmful pollutants such as heavy metals, microplastics, antibiotics, and viruses from water to guarantee a supply of clean water (N. Li et al., 2022). To address this issue, innovative methods for wastewater remediation, including adsorption, photocatalysis degradation, electrochemical treatment, and Advanced Oxidation Processes (AOPs), have been developed (Chen et al., 2019). These existing techniques for wastewater remediation heavily depend on functional materials, making cost-effective alternatives highly desirable. The development of materials derived from waste for wastewater remediation has experienced rapid expansion, holding substantial environmental and economic importance (Chen et al., 2022). In recent years, biomass and waste-derived carbon-based adsorbents have attracted considerable attention (Soffian et al., 2022). Carbonaceous substances constitute a highly advanced category of materials integral to modern material science and technology, playing an important role in industry due to their robust characteristics. Within environmental remediation, carbon-based materials hold significant promise (Nasir et al., 2018). The fusion of carbon-based materials with nanotechnology has introduced unique functionalities compared to their original forms. Engineered carbon-based materials have gained a remarkable attention in addressing global environmental challenges, with a particular emphasis on wastewater treatment. These materials have been effectively employed in water purification, demonstrating high efficiency in the removal of various environmental pollutants (Smith & Rodrigues, 2015). Graphene is a carbon allotrope with a single layer of atoms arranged in a two-dimensional hexagonal lattice and it finds extensive applications in wastewater treatment. Tohamy et al. (Tohamy et al., 2020) explored the adsorption of nickel (Ni(II)) on graphene oxide produced through a one-step oxidation process using various agricultural biomass sources (sugarcane bagasse, rice straw, mature pine wood sawdust, and lignin). The rice straw-based graphene oxide had the highest Langmuir Ni (II) uptake capacity at 7.75 mg/g, followed by mature pine wood sawdust (6.34 mg/g), lignin (5.66 mg/g), and rice straw (3.22 mg/g) derived graphene oxides. In another work, graphene oxide derived from polyethylene terephthalates found in waste plastic bottles exhibited significant Langmuir uptake capacity for methylene blue (867.2 mg/g) and acid blue-25 (641.4 mg/g) dyes (El Essawy et al., 2017). Gupta et al. have developed a graphene-like porous carbon nanostructure (BGBH-C-K) by utilizing Bengal gram bean husk (BGBH), an agricultural waste biomass, through alkali activation. Bengal gram bean, scientifically known as *Cicer arietinum* or chickpea, belongs to the Fabaceae family and is recognized for its nutrient-rich composition, including substantial amounts of protein, dietary fibers, and minerals. The BGBH- C-K, characterized by its graphene-like lamellar structure and abundant micropores, demonstrated significant potential for the adsorption of organic dyes from industrial water (Gupta et al., 2019). Goswami et al. published the first study on using rice straw-derived biochar as an eco-friendly substitute for graphite in the synthesis of Graphene Oxide Nanoplatelets (GONp) through the Hummers method. In this research, biochar derived from rice straw biomass (RSB), a widely produced agricultural waste, served as the primary material for GONp synthesis. The functional characteristics of these GONps were assessed based on their adsorption efficiency. Adsorption experiments were conducted using Crystal

Violet (CV), a common azine dye employed in the manufacturing of paint and printing industries (Goswami et al., 2017).

Lignin, constituting the second most abundant aromatic compound after cellulose, accounts for approximately 20 % of the world's organic carbon. It is the substance responsible for the woody characteristics of plants.

Recognized as a valuable material, lignin can be transformed into high-value products. Its cost-effectiveness, widespread availability, and versatile properties have captured the attention of researchers globally. Numerous studies focus on utilizing lignin and lignin-based materials for the removal of heavy metals from wastewater. For instance, Wu et al. (Wu et al., 2008) conducted adsorption using lignin as an adsorbent for the removal of Cr(III) from water. Srivastava et al. (1994) characterized lignin in its application to remove zinc and lead. Meng et al. (Meng et al., 2020) investigated the use of lignin-based adsorbents for the removal of azo dye from aqueous solutions.

Pine-derived adsorbents have been extensively studied due to their widespread availability on various continents and have been employed in numerous adsorption research in the literature. In a chapter by Philippou et al. (2021), it was concluded that pine biomass and waste, encompassing components like bark, needles, and cones, have effectively been utilized to create innovative adsorbents (raw, modified, activated carbon, etc.) for capturing toxic metal ions from wastewater. On the other hand, adsorbents derived from sunflower residue have proven to be highly efficient for decontaminating (waste) waters from dyes. Studies indicate that activated carbon produced from sunflower residues exhibits a higher adsorption capacity compared to the pristine form. This enhancement is attributed to the increased surface area and the presence of available functional groups on the adsorbent's surface (Anastopoulos et al., 2022).

Several studies have investigated the efficacy of corn cob as an adsorbent. Arunkumar et al. (2014) highlighted the significant role of corn cob as an effective absorbent for the adsorption of nickel (II). They observed an increase in adsorption capacity with a rise in the concentration of heavy metal ions, reaching a maximum of 70.08%. Research has indicated that incorporating active ingredients, such as zinc chloride, into corn cob can enhance the adsorption properties of activated biochars derived from raw biomass. In a study by Tsai et al. (1998), activated carbon was synthesized from corn waste (cob) using chemical activation with zinc chloride. The impregnation of zinc chloride into biochar was found to be crucial for adsorbing metal ions from wastewater, as it blended with biochar, forming activated carbon with a higher surface area due to its smaller particle size, resulting in increased adsorption efficiency.

Contaminated Soil Remediation

Soil contamination is a global concern and acts as a significant obstacle to sustainable development attenuating heavy metals in contaminated soil. It affects the equilibrium of ecosystem, leading to escalating economic losses and human health damage. Inadequate or irresponsible disposal practices, such as improper industrial discharge, mining tailings, waste disposal, and stockpiles, are the primary contributors to soil contamination. Common soil contaminants encompass heavy metals, toxic organic compounds, and radionuclides (Xu et al., 2019). To mitigate the high risks posed to human health and ecological security, it is essential to remediate contaminated soils for their recovery. Various remediation efforts, including the application of cutting-edge technologies, have been undertaken to achieve environmentally sound and cost-effective restoration of polluted lands (Mao et al., 2015).

Shellfish farming has become a globally expanding economic venture. However, the intensive production of shellfish results in substantial waste. Recycling shell waste proves to be a good alternative, addressing environmental concerns and providing economic benefits. Mussel shells, a plentiful by-product of the canning industry, constitute 32% of the animal's total weight and are particularly rich in calcium carbonate (Barros et al., 2009). Through calcination, these shells can be transformed into a useful calcium oxide catalyst (Benni et al., 2021). Notably, calcium carbonate surfaces, especially in the form of calcite, are known to adsorb metals like Zn^{2+}, Cd^{2+}, and Pb^{2+} (Jurinak & Bauer, 1956; McBride, 1980). Given its predominant composition of calcium carbonate, mussel shells serve as an ideal adsorbent for various heavy metals. Therefore, there are many works in the literature related to the decontamination of soil by mussel shells (Fernández-Calviño et al., 2014, 2018; Garrido-Rodriguez et al., 2014; Garrido-Rodríguez et al., 2013; Ramírez-Pérez et al., 2013). For instance, Ahmad et al. (2012). utilized mussel shells, cow bones, and biochar to mitigate lead (Pb) toxicity in heavily contaminated soil from a military shooting range in Korea. Their findings revealed that the tested amendments or soil dilution effectively reduced Pb availability in the military shooting range soil, thereby mitigating the risk of ecotoxicity (Ahmad et al., 2012). Ok et al. (2010). evaluated the utilization of oyster shell waste as a liming material in stabilizing metal-contaminated soil. Their study aimed to remediate soils contaminated with cadmium (Cd) and lead (Pb), which are often encountered in areas near abandoned mines, by employing oyster shell waste as a soil stabilizer (Ok et al., 2010). In the study that was published by Soares et al. (2015) it was aimed to evaluate the feasibility of using a compost obtained from composting industrial eggshell with other organic wastes, as a soil amendment for immobilization of Pb and Zn in acidic contaminated mining soil.

Air Pollutant Remediation

One of the most significant challenges of our time is air pollution, as it not only contributes to climate change but also has detrimental effects on public and individual health, leading to a rise in morbidity and mortality. Air contamination signifies alterations in the natural atmospheric composition resulting from the introduction of biological, physical, or chemical substances released from biogenic, geogenic, or anthropogenic sources. Both outdoor and indoor air contaminants might be present in particulate or gaseous forms. Particulate form encompasses small-sized masses with complex chemical constituents, ranging from nanometers to micrometers, including biologically originated aerosols like fungi, bacteria, and viruses. The gaseous form includes various chemical molecules such as ozone (O_3), sulfur dioxide (SO_2), and carbon monoxide (CO) (Manisalidis et al., 2020).

Poor air quality has detrimental effects on the natural environment, including living organisms and vegetation, as well as on human health. It is associated with various potentially fatal diseases, such as cardiovascular diseases, respiratory diseases, and cancer. According to the World Health Organization (WHO), air pollution causes approximately seven million deaths globally each year. WHO data reveals that nearly nine out of ten people breathe air with elevated levels of contaminants (WHO, 2018). Therefore, obtaining comprehensive information about air pollutant sources and developing innovative technologies for air remediation is crucial (Saleem et al., 2022). In this regard, solid adsorbents that derived from industrial wastes and their utilization for CO_2 capture were reviewed by Kaithwas et al. and Wang et al. (Kaithwas et al., 2012; J. Wang et al., 2019).

Serafin et al. (Serafin et al., 2021) conducted a study on the production of activated carbons using various biomass residues from the Amazonian fruit waste, for low-pressure CO_2 storage. Employing a two-step method with KOH activation, microporous activated carbons characterized by a significant volume of small pores were prepared using four different Amazonian biomasses (Cupuassu shells, andiroba seeds, assai seeds and Brazilian nutshells) as carbon precursors. The activated carbon derived from andiroba seeds exhibited the highest CO_2 adsorption at 1 bar, reaching 7.18 mmol/g at 273 K and 4.81 mmol/g at 298 K.

Fly ash (FA) is a byproduct, typically consisting of fine particles, generated from the flue gases of furnaces using pulverized coal. Maroto-Valer et al. (Mercedes Maroto-Valer et al., 2008) created two types of activated carbon-based adsorbents from fly ash with high content of LOI values (ranging from 59% to 97%) to capture CO_2 at different temperatures. These adsorbents were further modified with various amine compounds. Their findings indicated that steam treatment could increase the surface area of the synthetic adsorbent, while amine impregnation had the opposite effect, decreasing the surface area.

Coconut shell, being an excellent carbon precursor, is known for its high purity, lack of dust, and consistent porous structure. Son et al. (Son et al., 2005) produced carbon molecular sieves using coconut shell char as the primary material. They doped magnesium (Mg), calcium (Ca), cobalt (Co), copper (Cu), and nickel (Ni) onto the coconut char, followed by calcination at a specified temperature. Under conditions of 25°C and 1 bar, carbon molecular sieves synthesized from magnesium-impregnated coconut char exhibited a relatively high uptake performance for CO_2, reaching 2.23 mmol/g.

Almond shell is also considered as a raw material for the production of activated carbon. Plaza et al. (Plaza et al., 2011) created two types of activated carbon materials from almond shells intended for CO_2 adsorption. The study compared two modification approaches: conventional activation with CO_2 and heat treatment with ammonia gas. Both resulting samples exhibited commendable CO_2 uptake performance, demonstrated in both 100% CO_2 and a binary mixture containing 15% CO_2 in N_2.

Sustainability Reflections in Health and Environmental Management And Ultimate Remarks

In this chapter, various applications of waste materials in the field of healthcare and environmental management have been overviewed. Recently, the increased global concerns about the sustainability of Earth have brought increased attention to the public and industrial sectors regarding the damaging effects of chemical toxins and non-biodegradable materials. The accumulation of waste materials constitutes a growing problem, posing threats not only to the environment but also to public safety. Addressing this issue involves recycling and utilizing these waste materials in industries instead of disposing of them. Consequently, there is an urgent demand for the efficient transformation of wastes into useful materials, aiming to minimize the amount of waste released into the environment. While the idea of transforming waste into advanced technologies for environmental purposes appears attractive, there are substantial knowledge gaps related to engineered materials that need to be addressed before these concepts can be effectively implemented in the real world. These knowledge gaps include considerations about energy utilization, the generation of secondary wastes, the behavior of fate and transport, exposure routes in diverse environments, and toxicity levels across various organisms. Although functional materials can be derived through sustainable methods, it's essential to recognize that the sustainability of these materials doesn't guarantee their safety or assure that their use and release into the environment won't have adverse effects. The economic and functional advantages of composites created from renewable and sustainable resources should be complemented by proactive engagement from industry leaders and government officials to propel global expansion in this innovative category of materials, ensuring positive impacts on society, the environment, and the economy.

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