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Biogenic Materials and Wastes: A Sustainable Source of Clean Energy

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Abstract: Progress in agriculture and industry is taken as a general criterion for the development of any country, and this craze has resulted in unlimited exploitation of every bit of natural resources. The exploitation of natural resources includes biological and nonbiological waste. Wastes that are produced due to the exploitation of biological materials such as agro waste, rice husk, coconut shell, jatropha oil, banana peels, tea-tree extract, waste food, food products, insects, and chicken fat are known as biogenic waste. Biogenic materials can be used to minimize the environmental hazards produced through the exploitation of different nonbiogenic materials that are used by a larger number of populations in their daily life. Thus, biogenic materials can be used for the sustainable development of clean energy, as their production does not require industrialization. Currently, different types of biological materials are used in different sectors ranging from the construction sector to pharmaceuticals as well as food, biorefineries and agriculture. These materials, on the one hand, are proven to be very useful, as they have fulfilled the requirements with the goal of less environmental hazards in their production; they also have a dark phase with negative environmental impacts after their use. Modern research has led to the use of biogenic waste by transforming it into different types of nanomaterials that can be reused with minimum pollution and can be commercialized. This chapter includes different types of biomaterials and their uses along with biogenic wastes. The final section includes different types of transforming products of biogenic waste to nanomaterials along with their uses.
Keywords: Biogenic materials, clean energy, nanomaterials, transformation, environmental hazards.

I. INTRODUCTION

The growth and development of any country can be traced by the advances of the techniques employed in the country in different arenas, such as health, infrastructure, industries, education, agriculture and social life. Currently, one of the major challenges faced by developing countries in this century is to develop sustainable manufacturing models in industrial, agricultural, and different areas, as mentioned above [1]. The use of different types of agricultural and biological waste derived from the exploitation of living organisms can be employed as a valuable source of renewable raw materials (RRM) and commodities. The concept of biorefinery is being studied as a way to both decrease pollution and avoid the depletion of nonrenewable sources. Biomaterials are biodegradable, environmentally friendly and biocompatible. Additionally, being cost-effective, they can reduce the burden of being used in different arenas, as well as provide a sustainable solution to waste management. As the commencement of advanced techniques is being employed to reduce greenhouse and nonbiodegrable wastes, the use of biomaterial wastes promoted to produce green energy to fulfil the production demand without harming the environment [2]. For example, many studies have been performed to establish a biorefinery approach to volarise agricultural industrial wastes in the search for value-added materials and chemicals [3]. The multidisciplinary nature of biomaterials and their wastes has forced scientists to modify chemical processes, leading to greener methods that produce a reduction in the amounts of contaminating residues from the food industry, biomedical industries, and agricultural waste while being employed for the production of value-added products.

Finally, the application of nanotechnology for the fabrication of biomaterials and their derived wastes has proven to bring a radical change in different sectors with a special impact on biomedical technology[4]. Although synthetic biomaterials have long been employed in China and Roman culture for wound healing, nanobiotechnology has augmented their use in the fields of tissue engineering, organ transplantation, drug delivery, orthopedics, cardiovascular systems and dental plaque. In the following paragraphs, we discuss the different types of waste biomass, their sources and their utilization for human welfare.

II. WASTE BIOMASS: TYPES, SOURCES, AND APPLICATION

Waste biomass, such as lignocellulose materials (e.g., agricultural and forest residues), seed crops, energy crops, microalgae, food waste, and the organic fraction of municipal solid waste, has enormous potential to provide energy and value-added products via different conversion technologies. The source of biogenic wastes can be studied under the following headings.

A. Lignocellulose Biomass

Lignocellulose materials are cost-effective and carbon neutral feedstocks that can be derived from agricultural crop residues and forestry biomass. It contains cellulose (40-60 wt%), hemicellulose (20-40 wt%) and lignin (10-24 wt%). Agricultural waste is the residue produced by the harvesting and processing of agricultural vegetative crops. Since these crop residues are nonedible, they pose no competition to the food supply or fertile arable lands. Forestry biomass waste is derived from unused wood and utilized in the manufacturing sector, such as the household industrial construction and power sectors. As the biomass of lignocellulosic waste can be exploited for the production of carbon free energy as well as different valuable products, it can be considered a sustainable source of green and clean energy and has successfully drawn the attention of the government to enhance the cultivation of lignocellulosic agricultural plants and forests. Although some barricades restrain the utilization of agricultural and forest biomass throughout the year as seasonal, geographical and climatic variations determine their availability and cost, their cultivation can encompass a substantial probability to biofuel industries to fill the clean energy necessity. Some common energy crops include elephant-grass, switchgrass, Miscanthus, and hybrid poplar.

B. Oilseed Crops

Plant-based oilseed crops are important agrarian commodities. Several species of plants contain oil in the form of fatty acids, lipids, and triacylglycerol and are utilized by plants to grow their seedlings. The structural similarity of triacylglycerol with long chain hydrocarbon makes oilseed plants a suitable candidate for the foundation of a viable alternative to hydrocarbon-based products. Recent researchers have opened a new avenue by introducing techniques that employ conventional and nonconventional feed stocks, which include oils derived from various edible and nonedible plant sources, such as *Alinthus altisma* (heaven tree), *Azadirachta indica* (Neem), *Tatropha, Ricinum communis* (Castor), vegetable oil, olive oil, and soybean oil, to convert them into biodiesel by the application of biogenic waste-derived heterogeneous catalysts [5]–[7]. These catalysts may be chemical or biological in nature. Biological catalysts are mostly enzymes that have the capability for transesterification reactions and can produce biodiesel from feedstocks. Thus, these techniques can be considered economically viable techniques for biodiesel production and can be exploited to develop sustainable sources of clean and green energy.

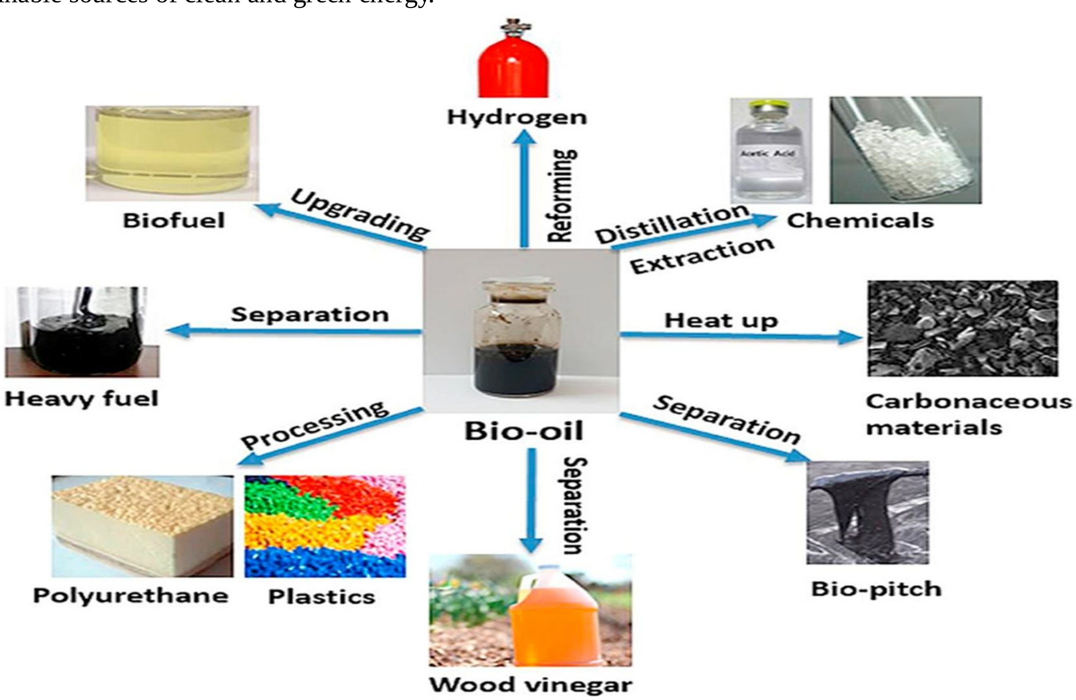

Figure 1. Different commercial products from bio-oil [8].

C. Municipal Solid Waste

The waste materials (e.g., garbage, recyclable and nonrecyclable residues) obtained from municipalities, including households, are known as municipal solid waste (MSW). MSW encompasses waste materials from different origins, such as large industries, hospitals, institutions, schools, colleges, universities, and many more household materials. It includes both biogenic and nonbiogenic materials, the composition of which depends on the origin, production pattern, household income and geographical location [9]. Mixed MSW typically represents a mixture of fossil organic (e.g., plastic) and biogenic materials (e.g., paper, cotton and wood products, food wastes) [10]. The increasing demand for renewable energy sources has prompted the Energy Information Administration (EIA) to examine renewable energy sources from municipal solid waste [11]. Biomass is an important resource for renewable energy [12]. Biogenic waste components in MSW may provide an important source for biomass, and it has been reported that nonbiogenic waste has a higher heat content per unit weight than combustible biogenic materials. Thus, the ratio of biogenic to nonbiogenic material volumes can have a considerable effect and has opened a new window for scientists for the production of clean and renewable forms of energy [11].

D. Food Waste

Food waste, an integrated part of the organic fraction of MSW, encompasses the area of biodegradable waste produced from various sources, including food processing plants, restaurants, kitchens and households. The generation of food waste can be estimated due to overproduction, damage to food items, including fruits and vegetables, by microorganisms, pests and insects, delayed consumption and overwhelming purchases [13]. According to an estimation, approximately 1.3 billion tonnes of food such as processed meat and vegetables from dairy products are lost through the food supply chain every year [14]. It has been reported that presently, food waste is landfilled or incinerated together with other combustible municipal waste in many countries for possible recovery of energy, but these processes are not cost effective or hazardous for our environment. To overcome this scenario, food waste with organic and nutrient-rich compositions, such as carbohydrates, lipids, fats, cellulose, hemicellulose and lignin, is converted to biofuel in a potential remedial approach [13]. Modern research reveals that fermentation is one of the important steps for the conversion of food waste to biofuels. The valorization of food waste has opened a route for the production of bioethanol [15], biobutanol [16], and biohydrogen [17]. As biohydrogen is gaining popularity, food waste can be exploited as eco-friendly and cost-effective feedback for its production through photo/dark fermentation and gasification. Pyrolysis is another approach by which food waste can also be converted thermodynamically to produce bio-oil and biochar [18] and hydrogen-rich syngas by hydrothermal gasification [13]. However, the fact that the composition of food waste, pretreatment methods and processing parameters influence the production of biofuels should be considered. Finally, we may conclude the session by considering that proper treatment of food waste can play a pivotal role to full-fill the increasing demand of carbon free energy on one hand while on other hand it reduces the municipal solid waste in an effective manner.

E. Animal Manure

Animal manure is the solid, semisolid, and liquid byproduct of livestock and poultry farming. Due to the presence of nutrient-rich metabolic waste, it has long been utilized as a fertilizer for the production of agricultural crops through traditional manure treatment composting and vermicomposting [19]. Moreover, animal manure could also contain different types of pathogens posing ecological risks, and it can also contribute to the emission of GHs (greenhouse gases), such as CH_4, by microbial decomposition [20]. Although the abovementioned conclusions may prove that animal manure is a poor candidate for biogenic waste for clean energy production, modern researchers have found that proper thermochemical treatment of animal manure can produce different types of biofuels, which may contribute to a pivotal role in clean and green energy production. Apart from these, bio-oils derived from animal manure can be used commercially for other purposes. Scientists have employed different methods to exploit animal manure for the sustainable production of energy; for example, fermentation and dark fermentation can be used for the production of bioethanol and biohydrogen, respectively [21], [22]. Pyrolysis is utilized in animal manure for the production of bio-oil [23]. Bio-oil can be commercialized for different purposes. Its processing under different conditions can be used for the production of different types of biofuels, heavy fuels, plastics, wood vinegar, and hydrogen gas. Different types of carbonaceous materials, biopitches and different types of chemicals [8]. Presently, hydrothermal liquefaction and hydrothermal gasification have been proven for the production of biocrude oil as well as syngas [24]. Volarization of horse manure through catalytic supercritical water gasification, which in turn can be exploited for the production of different types of biofuels, can play a major role in the production of energy resources employed for various purposes.

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Finally, we may conclude that animal manure can be exploited by various biological and physio-chemical techniques for the production of many valuable materials ranging from agriculture to daily commercial products as well as bioenergetic resources. The energy produced through animal manure can minimize carbon emissions and may play a pivotal role in minimizing the pollution of air, water and other natural resources.

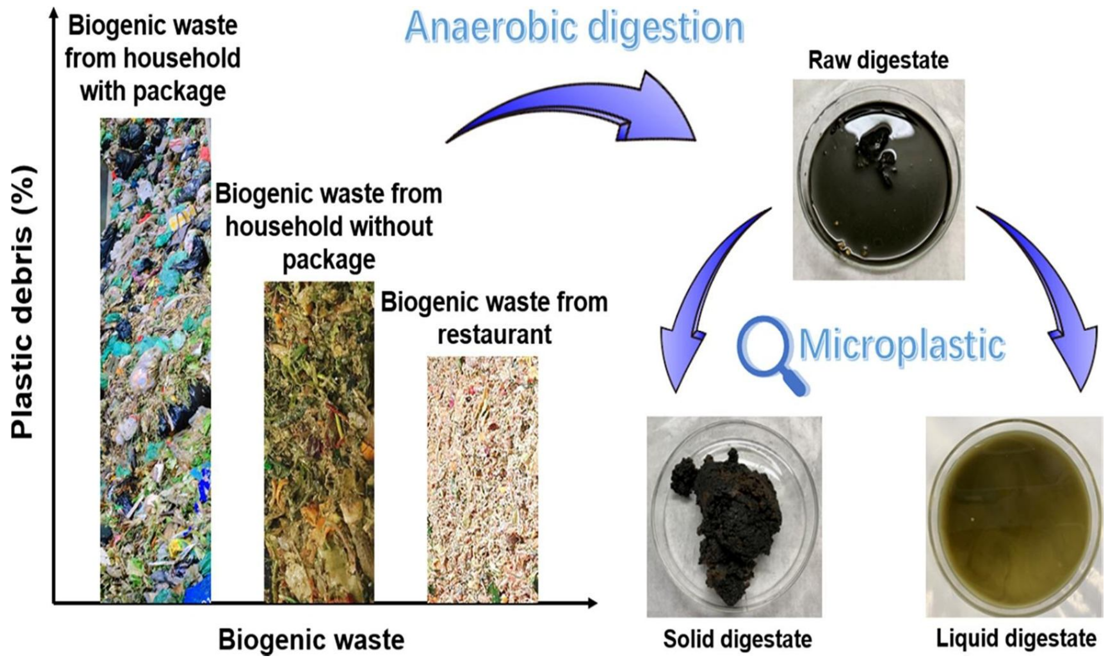

Figure 2. Different sources of biogenic wastes and anaerobic digestion produce solid and liquid digestate to produce different materials.[25]

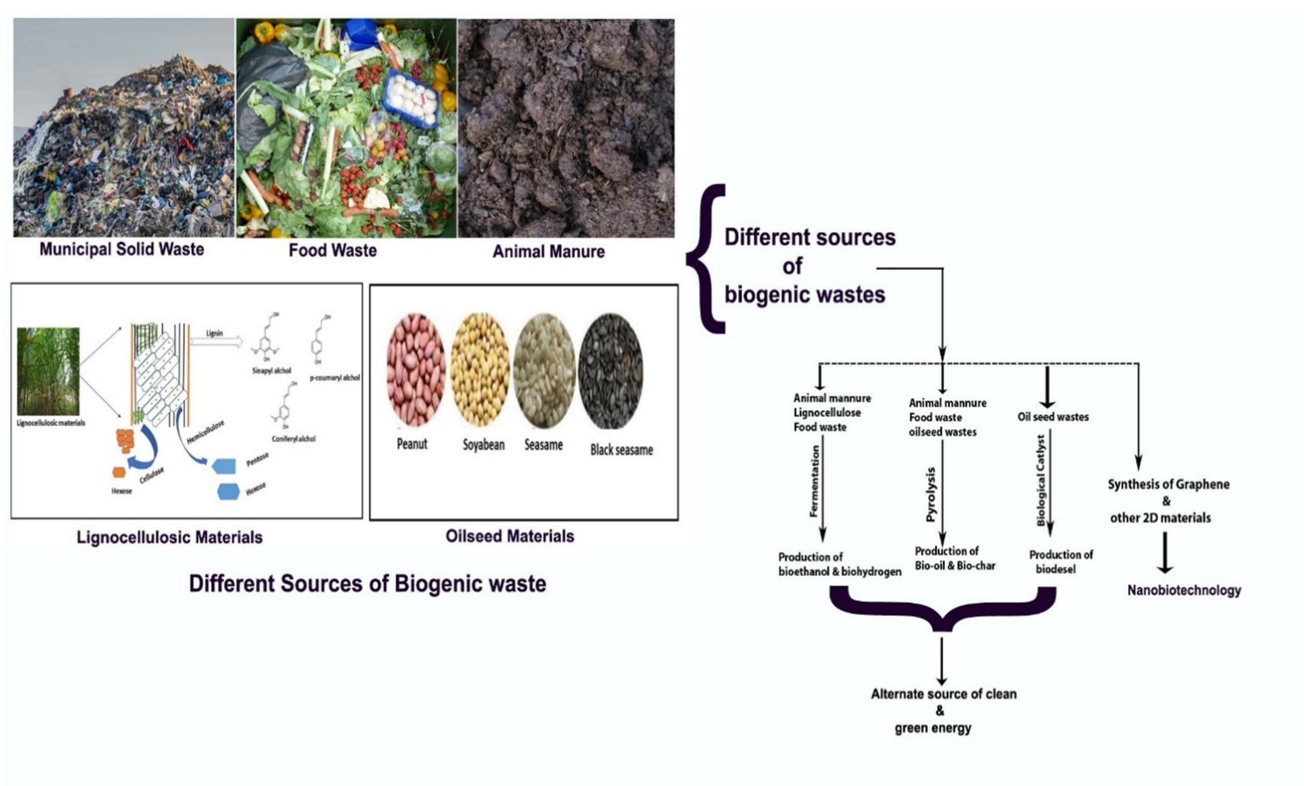

Figure 3. Different sources of biogenic wastes and their recycling to value-added products.

III. BIOGENIC WASTE AND ITS APPLICATION IN NANOTECHNOLOGY

Nanoscience is the application of physics, material science and biology for dealing with and manipulating materials at the atomic and molecular levels. The application of nanotechnology in the field of nanoscience can manipulate, assemble, control and manufacture materials at the nanometer scale. The field was subject to growing public awareness and controversy in the early 2000s, and in turn, this sector has proven itself to bring a radical change in every aspect of human beings [26]. Nanotechnologies contribute to almost every field of science, including physics, chemistry, material science, computer science, and engineering. The most advanced nanotechnologies used in recent years have been applied in the field of medical science, especially for cancer treatment.

As we have read, biogenic and nonbiogenic waste accumulated in the environment can create a harmful environmental issue for humanity/Earth, and a tremendous number of varieties of resources of different kinds are needed globally. In recent years, the application of nanotechnology for manipulating waste materials has been utilized for the production of an immense number of materials utilized in every era of life. Thus, on the one hand, nanotechnology reduces the adverse effect of waste accumulation, while on the other hand, it commercially opens a new avenue for sustainable development and a green economy.

Currently, a large number of efforts have been made to utilize waste materials for the synthesis of 2D materials in a greener way. Biogenic waste, including biomolecules such as coenzymes, enzymes, proteins, and terpenoids, is known to play an energetic role in the formation of a different variety of 2D materials and hence controls the protocol of green synthesis of 2D materials [27]. Biogenic waste is derived from crop residue, food waste, biomedical waste, and agro waste. According to an estimation, if the present situation continues, the expected generation of annual waste will be approximately 3.40 billion tons by 20250 [28]. Overwhelming of biogenic and nonbiogenic wastes is an alarming situation for scientists looking toward developing and deploying various technologies to reduce, reuse, recycle, and produce new materials utilizing waste for industrial applications and renewable sources of energy. The modern scientific community of nanotechnology is focusing on a sustainable environment. Nanotechnology has attempted to develop ground-breaking methods for the preparation of nanomaterials [29]. There are a variety of nanomaterials from 0D, 1D, 2D and 3D with diverse potential in science and technology and are synthesized by toxic hazardous and nonecofriendly chemicals. Thus, scientists have introduced the application of green chemistry to prepare nanoparticles from biogenic wastes, which will be cheaper and ecofriendly [30].

Graphene was the first two-dimensional (2D) nanomaterial discovered in 2004. [31]. It is a two-dimensional sheet of carbon atoms with a bonding pattern of sp^2 hybridization. It has unique properties, viz., high electrical conductivity, greater mechanical elasticity, high carrier transport mobility, a high young module, and high absorption of the white light spectrum. Thus, graphene has broad applications in diverse fields, including energy storage and conversion, optical devices, DNA sequencing, plasmonic sensors and hybrid materials [32]. Apart from graphene, other important 2D materials are hexagonal boron nitride (h-BN), graphitic carbon nitrate (g-C_3N_4) metal nitride carbides (MXenes). Presently, various approaches have been employed to synthesize graphene and graphene-like carbon materials by utilizing waste, biomass and bioprecursors [33]. According to the source of biogenic materials, the types of nanomaterials can also be subcategorized; for example, graphene sheets, interconnected carbon nanosheets and monolayer graphene are derived from chitosan, insects, hemp, glucose, food, paper waste, etc. Porous graphene and N- and B-doped graphene are synthesized from biomass such as sucrose, gelatin, coconut coir, shell, soybean shell, pine bark, bamboo char, wheat straw, and fungus through pyrolysis [27].

Two-dimensional (2D)-layered materials are a group of materials with sheet-like structures with transverse dimensions larger than 100 nm and thicknesses typically less than 5 nm. It has been found that by changing the thickness or layers, one can optimize the structural, optical, and electronic properties of novel 2D materials. The chemical bonding and crystal structure of 2D materials make them an ideal candidate for hybrid nanocomposites and sensors; on the other hand, the large lateral size and planar area of these materials can be exploited in surface active applications, including electrochemistry [34]–[36]. Overall, 2D-layered materials are considered to be a very significant material in terms of composition, crystal structures, properties, multifunctionalities, applications and low cost. These applications of 2D materials have forced scientists to develop different methods to synthesize 2D nanomaterials. Biogenic waste, such as agro waste, rice husk, coconut shell, jatropha oil, banana peels, tea-free extract, waste food, food products, insects and chicken fats, has been employed to develop 2D nanomaterials in a greener way. First, biogenic and nonbiogenic materials are undergoing pretreatment processes, physically (grinding and milling) then chemically (mainly by concentrated strong acids; HCl, HNO_3 H_2SO_4 followed by alkali) or by both according to the waste material to minimize the size of waste materials as well as to reduce the toxic effects of materials [27], [37], [38]. After pretreatment according to the waste materials, the pretreated materials undergo conventional and nonconventional methods for the synthesis of 2D materials. These techniques are categorized as chemical vapour deposition (CVD), hydrothermal methods, chemical exfoliation, and electrochemical exfoliation methods to make various types of 2D nanomaterials.

IV. SUMMARY & DISCUSSION

In the above paragraphs, we have seen that an over-exceeding population of the world resulted in overexploitation of natural resources to fulfil the energy demand. As natural resources are limited, the ecological footprint analysis revealed that the biosphere's ability to regenerate resources is unable to overcome the natural balance, resulting in an imbalance in the ecosystem. Apart from this, the utilization of natural energy resources to fulfil our energy demand is responsible for increasing pollution, which also affects human health as well as the natural ecosystem. On the other hand, the exploitation of biogenic and nonbiogenic materials by human beings results in the production of different types of biogenic and nonbiogenic waste, which must be recycled to avoid the casualties generated by their accumulation in the environment. Considering these above situations, scientists are trying to develop different strategies to exploit biogenic and nonbiogenic waste for the production of green energy, which will be cost effective and will be useful for the recycling of waste to produce value-added products without environmental hazards.

The different types of sources for biogenic waste include lignocellulosic materials derived from agricultural crop residues, forestry biomass, hydrocarbons derived from nonedible oil-seed plants such as *Alinthus altisma* (heaven tree), *Azadirachta indica* (Neem), *Tatropha,* and *Ricinum communis (Castor),* vegetable oil, municipal solid wastes (paper, cotton, wood products and food wastes) and food waste, which mainly contain organic biomass derived from the food industry. Various techniques, such as pyrolysis and fermentation under different conditions, have been employed by scientists to recycle and reuse these biogenic wastes to convert these wastes into useful energy resources, such as hydrogen gas and biodiesel. Encouraging these projects in Central Governments and State Governments has sanctioned considerable money in recent years. Most advances in biogenic waste have been found in the field of nanotechnology. Scientists have utilized fabrication techniques to synthesize biogenic waste materials into different types of nanomaterials, which can be 0D, 2D, 3D, etc. The most advanced 2D material synthesized by using nanotechnology with biogenic waste is graphene. These 2D nanomaterials are used in different fields, such as electronic chips, biological chips, biosensors, etc. The most useful arena of these nanomaterials is in medical sciences, which can bring a radical change in the medical field.

Thus, from the above discussions, we can conclude that biogenic waste can be utilized in different aspects, and proper management of this waste with suitable strategies can bring a pivotal change in human civilization in which the exploitation of our daily used materials can be recycled to minimize environmental pollution while reducing the overexploitation of natural resources to balance our ecosystem.

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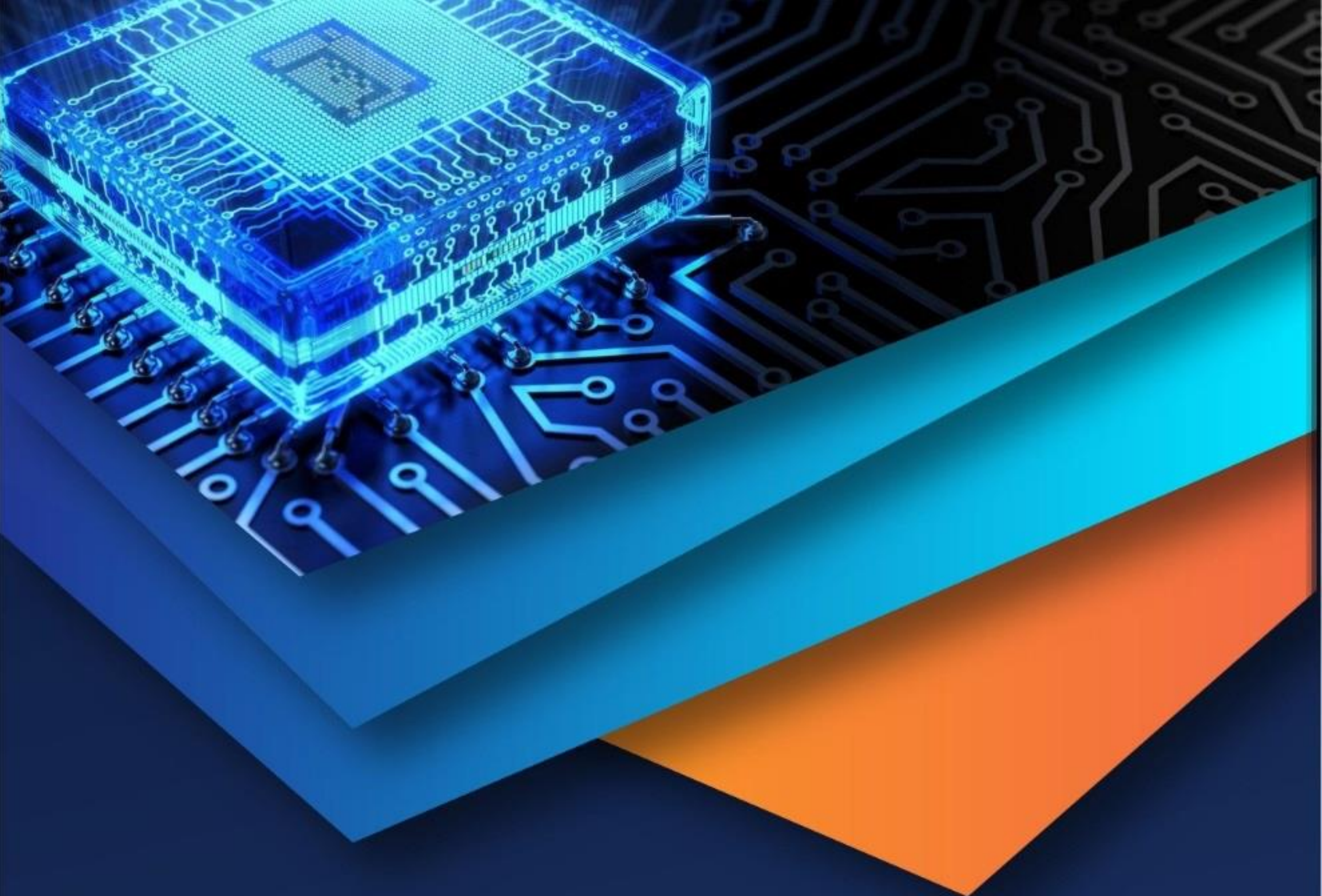

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