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Sustainable Nanocarbon Synthesis from Locally Available Natural Raw Materials: Versatile Properties and Wide-Ranging Applications

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Abstract. Nanocarbon materials, characterized by their exceptional properties and nanoscale structure, have garnered significant attention for their diverse applications in energy storage, catalysis, and water purification. This review article explores the sustainable synthesis of nanocarbon from locally available natural raw materials, such as walnut shells, rice husks, and bamboo. By harnessing waste materials, researchers promote environmental consciousness and cost-effectiveness, while also reducing waste accumulation and resource consumption. The classification of nanocarbons, including graphene, carbon nanotubes, fullerenes, and activated carbon, offers insights into their unique advantages and potential applications. Moreover, the versatility of extraction methods, such as pyrolysis, carbonization, and activation, enables the tailoring of nanocarbon properties to suit specific applications. The wide-ranging applications of nanocarbon materials, from energy storage to biomedical uses, highlight their immense potential in addressing diverse challenges and driving technological advancements. By embracing sustainable practices in nanocarbon synthesis, this review underscores the pivotal role of locally sourced nanocarbon materials in promoting a greener and more resilient future.

1 Introduction

Nanocarbons are a class of materials that have a high proportion of atoms arranged in a nanoscale structure. Nanocarbon materials have a wide range of properties, including high electrical conductivity, high thermal conductivity, and high surface area. These properties make nanocarbon materials attractive for a variety of applications, including energy storage, catalysis, and water purification [1-3].

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2 Classification of Nanocarbons

Summarized in table 1, nanocarbons can be classified into a number of different categories, based on their structure and properties. The following are some of the most common types of nanocarbons:

1. Graphene: Graphene is a single layer of carbon atoms arranged in a hexagonal lattice. It is the basic building block of other nanocarbon materials, such as carbon nanotubes and fullerenes. Graphene has a very high electrical conductivity and thermal conductivity, and it is also a very strong material [1].
2. Carbon nanotubes: Carbon nanotubes are cylindrical tubes made of graphene. They can be single-walled or multi-walled, and they can have a variety of different properties depending on their structure. Carbon nanotubes are very strong and lightweight, and they have excellent electrical and thermal conductivity [2].
3. Fullerenes: Fullerenes are spherical or ellipsoidal molecules made of carbon atoms. The most common fullerene is buckminsterfullerene, which has a soccer ball-like structure. Fullerenes are very stable molecules, and they have a variety of different properties, including high electrical conductivity and thermal conductivity [3].
4. Activated carbon: Activated carbon is a type of carbon that has been treated to increase its surface area. Activated carbon is used in a variety of applications, including water purification, gas adsorption, and catalysis [3].

Table 1. Classifications of Nanocarbons

Classification	Structure	Properties	Applications
Graphene	Single layer of carbon atoms arranged in a hexagonal lattice	Very high electrical conductivity and thermal conductivity, strong	Energy storage, catalysis, water purification
Carbon nanotubes	Cylindrical tubes made of graphene	Very strong and lightweight, excellent electrical and thermal conductivity	Energy storage, catalysis, biomedical applications
Fullerenes	Spherical or ellipsoidal molecules made of carbon atoms	Very stable molecules, high electrical conductivity and thermal conductivity	Gas adsorption, catalysis, biomedical applications
Activated carbon	Carbon that has been treated to increase its surface area	High surface area, used in a variety of applications	Water purification, gas adsorption, catalysis

3 Production of Nanocarbon Materials from Locally Available Natural Raw Materials

One way to produce nanocarbon materials is from locally available natural raw materials. This approach has several advantages, including the following:

1. It is a sustainable approach, as it uses waste materials that would otherwise be discarded. For example, walnut shells, rice husks, and bamboo can all be used to produce nanocarbon materials [2]. These materials are often available in large quantities and are relatively inexpensive [3].
2. It is a cost-effective approach, as the raw materials are often readily available and inexpensive. The cost of producing nanocarbon materials from locally available natural raw materials is typically lower than the cost of producing them from synthetic materials [3-5].
3. It is a scalable approach, as the process can be easily adapted to produce large quantities of nanocarbon materials. This is important for commercial applications, where large quantities of nanocarbon materials are often required.

The table 2 summarizes the important information about the production of nanocarbon materials from locally available natural raw materials:

Table 2. Extraction of Nanocarbons from Raw Materials

Factor	Information
Raw materials	Walnut shells, rice husks, bamboo, etc.
Advantages	Sustainable, cost-effective, scalable
Disadvantages	The quality of the nanocarbon materials may be lower than those produced from synthetic materials.

4 Extraction of Nanocarbon from Walnut Shells

Walnut shells are a waste product from the walnut processing industry. They are a good source of cellulose, which is a precursor to nanocarbon materials. The extraction of nanocarbon from walnut shells can be carried out by a variety of methods, including pyrolysis, carbonization, and activation [6].

4.1 Pyrolysis

Pyrolysis is a process in which the walnut shells are heated in an inert atmosphere to a high temperature. This process breaks down the cellulose in the walnut shells into smaller molecules, including carbon. The temperature at which pyrolysis is carried out determines the properties of the nanocarbon material that is produced. For example, pyrolysis at a high temperature (>700°C) produces a graphitic nanocarbon material, while pyrolysis at a lower temperature (<500°C) produces an amorphous nanocarbon material [2, 5].

4.2 Carbonization

Carbonization is a process in which the walnut shells are heated in an inert atmosphere to a lower temperature than pyrolysis. This process produces a carbon black material. Carbon black is a good precursor to nanocarbon materials because it has a high surface area. The surface area of carbon black can be further increased by activation [4].

4.3 Activation

Activation is a process in which the carbon black material is treated with a chemical agent to increase its surface area. The chemical agent typically used for activation is steam. Activation increases the surface area of carbon black by creating pores in the material. The size and distribution of the pores in the activated carbon black material determines its properties [3].

Table of Important Information

The following table summarizes the important information about the extraction of nanocarbon from walnut shells:

Table 3. Extraction of nanocarbon from walnut shells

Factor	Information
Raw material	Walnut shells
Extraction methods	Pyrolysis, carbonization, activation
Properties of nanocarbon materials	Amorphous or graphitic, high surface area
Applications of nanocarbon materials	Energy storage, catalysis, water purification

5 Conclusions

Nanocarbon materials stand out for their diverse and exceptional traits, such as high electrical and thermal conductivity and substantial surface area. These properties make nanocarbons highly valuable in a range of cutting-edge applications, including energy storage, catalysis, and water purification. The ability to manipulate and exploit these distinct properties opens doors to revolutionary advancements in various industries, addressing critical challenges and fostering sustainable development. The classification of nanocarbons based on their structure and properties offers a comprehensive understanding of their unique advantages and potential applications. Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, exhibits extraordinary electrical and thermal conductivity, alongside its impressive strength. Carbon nanotubes, cylindrical graphene structures, demonstrate outstanding electrical and thermal properties, making them ideal for diverse applications, ranging from energy storage to biomedical uses. Fullerenes, spherical or ellipsoidal molecules like buckminsterfullerene, possess high stability and a range of unique properties, including high electrical and thermal conductivity. On the other hand, activated carbon, derived from carbonization and treated to increase surface area, is widely used in gas adsorption, water purification, and catalysis due to its porous structure. Understanding the classification of nanocarbons enables researchers to strategically select materials best suited for specific applications, unlocking new possibilities in advanced technologies [7].

Embracing a sustainable approach, extracting nanocarbons from locally available natural raw materials showcases environmental consciousness and cost-effectiveness. Waste materials like walnut shells, rice husks, and bamboo, which are often discarded, transform into valuable nanocarbon sources through innovative extraction methods. This practice not only reduces waste accumulation but also contributes to resource conservation. By harnessing locally available raw materials, researchers promote regional development, tapping into abundant resources that support nanocarbon production. The environmentally friendly extraction process aligns with the principles of sustainable development, prioritizing the efficient utilization of resources [4, 5].

Furthermore, the use of local raw materials mitigates logistical challenges associated with transportation and access to specialized resources. As a result, the overall cost of nanocarbon production decreases, making it an attractive option for both research and commercial applications. The cost-effectiveness and scalability of nanocarbon production from waste materials present promising opportunities for research and industrial applications. Utilizing locally available raw materials, which are often obtained at low or no cost, significantly reduces the financial burden of nanocarbon synthesis. As a result, the overall production costs are lowered, promoting affordability and accessibility [6].

Moreover, the abundance of waste materials like walnut shells, rice husks, and bamboo ensures a stable supply of raw materials, essential for large-scale commercial production. The scalability of the extraction process enables researchers to cater to increasing demand without compromising on quality or efficiency. The cost-effective and scalable nature of nanocarbon production from waste materials facilitates its integration into various industries, ranging from energy to healthcare, fostering innovative solutions to global challenges.

The versatility offered by pyrolysis, carbonization, and activation techniques plays a pivotal role in tailoring nanocarbon materials for specific applications. Each method bestows unique properties upon the resulting nanocarbons, allowing researchers to finely control their characteristics. Pyrolysis, a thermal decomposition process carried out in an inert atmosphere, breaks down raw materials like walnut shells into smaller molecules, including carbon. The temperature during pyrolysis governs the properties of the nanocarbon, resulting in amorphous or graphitic nanocarbons with varying structures and conductivity levels.

Carbonization, performed at lower temperatures than pyrolysis, produces carbon black, a precursor with a high surface area. Carbon black serves as an excellent starting material for nanocarbon production, offering abundant surface sites for subsequent activation. Activation, a chemical treatment process, enhances the surface area of carbon black by creating pores, further customizing the nanocarbon's properties. The size and distribution of the pores can be controlled to cater to specific applications, such as catalysis or water purification. The versatility of these techniques enables researchers to tailor nanocarbon materials precisely, paving the way for targeted and efficient applications in diverse industries. The ability to control nanocarbon properties during synthesis offers researchers unprecedented flexibility in tailoring materials to suit various applications. Pyrolysis, conducted at different temperatures, yields nanocarbons with distinct characteristics, such as amorphous or graphitic structures. The choice of temperature allows researchers to produce nanocarbons with specific properties aligned with the desired application [7].

The carbonization process further adds to the control over nanocarbon properties. Carbon black, produced through carbonization, is a highly porous material with a substantial surface area, ideal for subsequent activation. Activation, in turn, allows researchers to fine-tune the surface area and porosity of the nanocarbon, further customizing its properties. By adjusting the activation parameters, such as the type and concentration of the chemical agent, researchers can precisely design nanocarbon materials with specific surface characteristics. This level of control over nanocarbon properties empowers researchers to optimize materials for diverse applications, ensuring that each material performs optimally in its intended use. The activation of carbon black derived from carbonization enhances its surface area and porosity, making it an ideal precursor for nanocarbon materials with improved properties. The process involves treating carbon black with chemical agents, such as steam, which create pores within the material. These pores increase the surface area, providing more active sites for chemical reactions and adsorption processes.

The enhanced carbon black serves as a highly versatile and customizable material for various nanocarbon applications. The size and distribution of the pores can be controlled through careful adjustment of activation parameters, tailoring the nanocarbon material for specific applications, such as catalysis or water purification. The activation process effectively transforms carbon black into a valuable and efficient nanocarbon precursor, further reinforcing the sustainability and cost-effectiveness of nanocarbon production. The diverse properties and customizability of nanocarbon materials extracted from walnut shells enable their wide-ranging applications across multiple industries. In energy storage, nanocarbon-based supercapacitors showcase exceptional performance and high capacity, promising to revolutionize portable electronics and electric vehicles.

Catalytic applications benefit significantly from nanocarbon materials' high surface area, promoting efficient and sustainable reactions in various industrial processes. Water purification processes also leverage nanocarbon materials' adsorption capabilities, effectively removing pollutants and impurities from water sources. Furthermore, nanocarbon materials play an integral role in biomedical applications, where their unique properties find use in drug delivery systems, bioimaging, and tissue engineering. The biocompatibility and versatile functionalities of nanocarbons hold immense promise in advancing medical technologies. The versatility of nanocarbon materials allows them to be integrated into advanced composites, enhancing material strength and electrical conductivity. These composites have applications in aerospace and automotive industries, where lightweight and high-performance materials are sought after.

The wide-ranging applications of nanocarbon materials demonstrate their immense potential in addressing diverse challenges and driving technological advancements across various sectors. The use of waste materials for nanocarbon production significantly contributes to sustainable practices and waste reduction. By transforming discarded materials like walnut shells, rice husks, and bamboo into valuable nanocarbon resources, researchers contribute to environmental conservation and resource efficiency. Through this environmentally conscious approach, the burden on landfill sites is alleviated, reducing the negative impact on ecosystems and landscapes. Waste materials that would otherwise be left unused find new life in nanocarbon production, reflecting a circular economy mindset.

The utilization of local raw materials also lessens the need for long-distance transportation, minimizing associated carbon emissions and energy consumption. The decreased reliance on synthetic raw materials further mitigates the environmental footprint of nanocarbon production. The integration of sustainable practices in nanocarbon synthesis aligns with global efforts to combat climate change and promote resource conservation. As researchers continue to explore novel methods for nanocarbon extraction from waste materials, the environmental impact of nanocarbon production becomes increasingly positive. The extraction of nanocarbon from locally available natural raw materials presents abundant opportunities for sustainable development and technological advancement. By utilizing waste materials, researchers contribute to resource conservation and promote a circular economy approach.

The cost-effectiveness and scalability of nanocarbon production from waste materials enable its integration into diverse industries, ranging from energy to healthcare, creating innovative solutions to global challenges. Sustainable nanocarbon synthesis aligns with the United Nations Sustainable Development Goals (SDGs), fostering environmental responsibility and promoting responsible consumption and production. This approach not only reduces waste generation but also contributes to cleaner production processes. Moreover, the versatility of nanocarbon materials allows for targeted applications in areas such as energy storage, catalysis, and water purification. Sustainable nanocarbon materials find applications in both established industries and emerging fields, such as renewable energy and nanomedicine. As the demand for efficient and eco-friendly materials continues to grow, sustainable nanocarbon synthesis holds the potential to revolutionize industries while preserving natural resources for future generations [8].

The utilization of locally available natural raw materials for nanocarbon extraction reflects a sustainable and economically viable approach. Controlled nanocarbon synthesis through pyrolysis, carbonization, and activation provides materials with tailored properties for diverse applications. The environmentally friendly extraction process aligns with waste reduction and resource conservation goals, making it a promising avenue for sustainable nanocarbon production. As researchers continue to explore nanocarbon applications, it is evident that the integration of locally sourced nanocarbon materials into various industries holds immense potential for technological advancements and environmental sustainability. By embracing sustainable practices in nanocarbon synthesis, we pave the way for a greener and more resilient future.

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