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# Generation of Green Carbon Nanomaterials from Biomass Pyrolysis for the Production of Biofuel and Bioenergy

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## Abstract

*The need to find a Renewable Energy Resource (RER) with significant potential has been brought to light by the fact that petroleum and natural gas are being used up to their full capacity, reducing the amount of energy produced globally. The issues relating to the preparation, hydrolysis with enzymes, and biomass culture processes that must be completed before bioenergy may be produced are still being addressed via ongoing initiatives. Because nanotechnology offers unique active areas for multiple responses and operations, it can overcome the difficulties posed by these biomass sources. Pyrolysis may be used to produce chemicals and RER from biomass sustainably. However, the process's high production expenses prevent it from being widely used. This approach's long-term reliability and financial viability may be greatly increased by fabricating high-quality, active carbon nanoparticles using waste heat and renewable progenitors. This paper suggests using Biomass Pyrolysis to Generate Green Carbon Nanomaterials (BP-GGCN) for biofuel and bioenergy production. The suggested method makes the most of biomass pyrolysis's financial gains and sustainability by producing superior Three-Dimensional Graphene Bubbles (3DGBs) using residual pyrolysis gases and thermal waste. The resultant 3DGBs work well in energy storage and ecologically sensitive applications. According to a life-cycle study, the current approach has less overall effect than the traditional Chemical Vapour Deposition (CVD) technique on human well-being, environmental systems, and resources. The specific qualities of this GGCN help biofuels, biodiesel, enzymes, and microbial fuel cells work better.*

***Keywords:*** *Carbon nanomaterials, pyrolysis, biomass, biofuel, bioenergy, Graphene bubbles.*

## Introduction

The prevailing fundamental energy consumption is mainly driven by traditional energy sources, namely petroleum, natural gas, and coal. This dominance gives rise to sustainability challenges, encompassing diminishing fossil fuel reserves, environmental repercussions, and significant price volatility [1]. The pressing issues of Greenhouse gas emissions (GHG), global warming, and high need for energy have motivated a cadre of experts to devise innovative alternatives to supplant the use of fossil fuels. Biomass constitutes around 82% of the energy RER generates worldwide, making it a prominent alternative power source. It can be preserved and utilized to create heat, fuel, and power. The term "bioenergy" refers to fuels derived from biological sources, including solids, liquids, and gases.

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The exceptional characteristics of graphene, including its superior electrical and thermal conductivity, substantial surface area, and impressive durability, have garnered significant interest in several domains, including power storage components, catalytic reactions, visible conductive films, and thin-film materials [2]. Nevertheless, most of these applications require a substantial quantity of graphene components in terms of volume or weight. Consequently, two-dimensional (2D) graphene films or specific graphene nanosheets must be expanded into the third dimension to construct a three-dimensional (3D) macroscopic framework. Numerous techniques have been devised for the fabrication of 3DGB. These include CVD utilizing commercially available nickel or copper foams, pyrolysis employing templates such as sodium chloride, small particles of polypropylene, or transparent silicon crystals, and the self-assembly of Graphene Oxide (GO) through hydrothermal processes. Nevertheless, it is important to acknowledge that these methodologies have certain drawbacks. For instance, they cannot manipulate pore architectures effectively, cannot exist independently, exhibit suboptimal mechanical strength, and frequently need intricate preparation procedures [3].

Despite several scientific advancements, some technological obstacles must be addressed to enhance the competitiveness of bioenergy production relative to fossil fuels. In the context of microalgal biofuel generation, several key factors remain unresolved, including the productive and effective growing of algae on huge scales, the preservation of desirable cultures with non-native species, the price of algae harvesting, power efficiency considerations, and the optimal method for converting algae into biofuels. In addition, before the biofuel-generating procedures, it is necessary to employ pretreatment technologies to remove fermented sugars from lignocellulosic biomass. In addition to technological limitations in production, there are evident challenges, such as inadequate physical facilities for the manufacturing process and comparatively high production costs concerning the initial generation of biofuels [4]. The limitations mentioned above underscore the need to formulate and implement generation and optimization strategies to attain optimal levels of bioenergy output while ensuring superior quality. One potential avenue for enhancing bioenergy production's efficiency and cost-effectiveness involves exploring processes related to prior treatment, enzymes, and fermentation [5].

Nanomaterials serve as the foundational concept for the application of nanoscience and nanotechnology. The field of nanostructure encompasses a broad multidisciplinary domain of study and development that has shown significant global growth in recent years. Nanoscale compounds can be characterized as a group of substances in which at least one dimension measures less than 100 nm. The diminutive dimensions of this entity result in a significant surface area-to-volume ratio, hence augmenting the number of active sites available for a multitude of reactions and activities. Nanoparticles (NPs) can manifest diverse morphologies, expanding their use across several domains.

Furthermore, it has been observed that nanostructured compounds have a higher reactivity rate with different molecules when compared to larger particles [6]. The commercial impact of nanomaterials has already been substantial, and their awareness is expected to increase due to their distinctive optical scale properties. These properties have significant implications for various fields, including bioenergy, electronics, mechatronics, medicine, pharmaceuticals, ionic liquids, polymers, etc.

Numerous direct and indirect utilization of nanomaterials in bioenergy generation have been documented. Nanomaterials have remarkable potential as viable options in many biofuel systems owing to their expansive surface areas and distinctive attributes, such as elevated catalyst activity, crystallization, resilience, effective storage, security, and adsorption capacity [7]. Nanoparticles, commonly employed as catalysts, contribute to the augmentation of anaerobic consortia's activity by mitigating inhibitory chemicals and facilitating electron transport, boosting process yields [8].

This study proposes a research or industrial procedure that seeks to employ biomass via pyrolysis for ecologically sustainable production of carbon nanomaterials. Carbon nanoparticles possess a wide range of possible uses, which may encompass the enhancement of productivity and environmental responsibility in biofuel and bioenergy manufacturing processes. This study and technological development follow the utilization of RER for electricity generation while mitigating potential ecological consequences.

## The Present State of Nanomaterials Generated from Biomass and their Applications

The procedure of converting biomass waste into products with added value, including gases, crude oil, and pulverized carbon content, involves several steps and is characterized by its complexity.

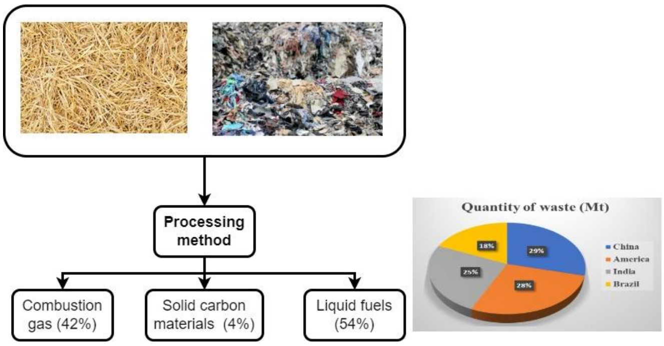


Figure 1(a): The biomass feedstock utilized and the transformation technique employed to determine the three fundamental elements of solid, liquid, and gas.

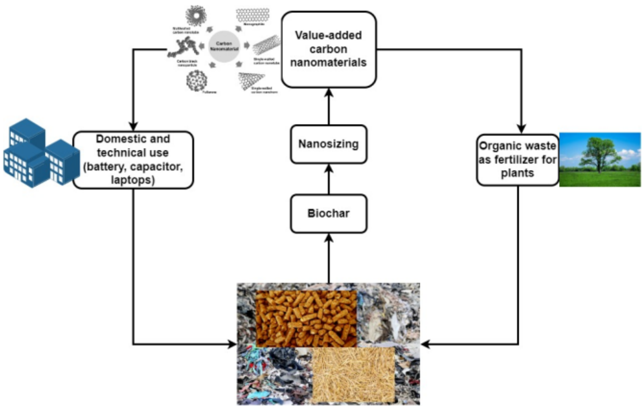


Figure 1(b): Framework for a circular economy using biomass waste management.

The biomass feedstock utilized and the transformation technique employed to determine the three fundamental elements of solid, liquid, and gas (Fig. 1a). According to the database, the proportion of carbon micro/nanomaterials in the overall value-added goods derived from biological waste is around 3-5%. Over the last twenty years, there has been a growing interest in biochar and carbon nanomaterials, leading to a substantial increase in the production process. This can be attributed to adopting a circular economy approach, which emphasizes the reuse and recycling of materials. As a result, the current situation and potential commercial applications of these pulverized materials, which constitute approximately 3-5% of biomass waste, have undergone significant transformation, as illustrated in Fig. 1b.

Fig. 1a shows the increasing possibility of agricultural biomass waste in the world's top four nations. These residues hold promise as valuable RER and novel materials characterized by distinctive surface topologies [9]. China has been recognized for its significant usage of biomass and associated waste as a reusable resource since 2014. Similarly, India has made notable progress in manufacturing biofuels, including biodiesel and other alcohols as energy sources, from biomass between 2015 and 2020 [10]. The administration of the waste from biomass was first used to promote environmental cleanliness and reduce the space occupied by the disposal of such trash. Over time, it has evolved into a means of generating RER and producing new carbon resources.

It is worth noting that from the inception of industrialization, scientists and researchers have made concerted efforts to transform diverse waste resources such as metals, polymers, biomass, and others into valuable commodities [11]. The transformation of biomass waste and associated resources into reusable goods garnered significant interest in the 1980s. According to existing literature, the period from 1990 to 2018 witnessed a considerable focus on using biomass waste to produce various valuable outputs such as biofuels, biogas, fossil fuels, and organic matter. This research primarily included both micro and macro settings. Furthermore, at the same time, significant technological advancements were made in relation to the transformation of bulk biomass.

Based on Fig. 1a and 1b, it is evident that the utilization of biomass and its related waste as a viable resource for green materials in the realm of RER and other beneficial products is flourishing. Furthermore, exploring practical carbon nanomaterials produced from biomass waste presents numerous novel avenues for further investigation. The utilization of biomass waste in manufacturing value-added commodities offers several significant benefits, including its cost-effectiveness and abundant availability, as well as its potential for mitigating GHG emissions [12]. However, some significant limitations and obstacles are associated with biomass, including very modest or reduced processing output, inadequate energy content, and poor bulk density. It is worth noting that some products, such as biochar, nano fertilizers, nanomaterials, biofuel, and biogas, have already been introduced into the market for various practical purposes and technical applications [13].

In recent times, there have been advancements in the fabrication of methodologies, prototype devices, and nanomaterials at both milligram and gram scales, with the potential for future upscaling. There is a pressing need for substantial financial support and rigorous investigation into both fundamental and practical aspects of nanomaterials generated from biomass waste. For instance, the first nanomaterials obtained from biomass exhibited significant challenges regarding limited surface area and porosity due to the extensive aggregation and coagulation of particles during the final product formation. However, it is worth noting that these issues have been successfully addressed, leading to the development of nanomaterials produced from biomass that possess an exceptionally large surface area.

## Generation of 3DGBs using BP-GGCN from Biomass Waste

The manufacture of 3DGB through biomass waste entails a series of procedures and the utilization of specific equipment, known as the "APCVD-catalytic purification" method. Presented is a simple block diagram illustrating the fundamental steps of this procedure.

Step 1: The use of biomass waste as a feedstock.

This marks the initial stage of the procedure. Biomass waste, encompassing various substances like lignin, cellulose, wheat straw and sawdust, and other forms of organic waste, is utilized as the primary input for producing 3DGB.

Step 2: Biomass pretreatment

The process of biomass pretreatment is a crucial step in the conversion of biomass into biofuels or other value-added products. Pretreatment procedures, such as drying and size reduction, may facilitate biomass waste's subsequent processing.

Step 3: Fast pyrolysis

The fast pyrolysis reactor is used to subject biomass waste to quick heating at elevated temperatures, generally from 400 to 600°C, in oxygen-depleted conditions—consequently, the thermal breakdown of biomass yields bio-oil, syngas, and biochar.

Step 4: Biomass gasification (syngas formation)

The process of biomass gasification involves the conversion of biomass into a gaseous fuel through a thermochemical reaction. Subsequently, the biomass that has been appropriately processed is exposed to a gasification procedure. Gasification entails subjecting biomass to high temperatures while introducing a carefully regulated quantity of oxygen or steam. The process yields syngas, sometimes called synthesis gas, including carbon monoxide (CO) and hydrogen ($H_2$), among other impurities.

Step 5: Syngas purification

The purification of syngas is a crucial process in the production of clean and high-quality synthesis gas. The syngas produced contain contaminants that must be eliminated to proceed with the succeeding stages. The process of catalytic purification, specifically Atmospheric Pressure Chemical Vapor Deposition (APCVD) -catalytic purification, is employed to cleanse the syngas.

A catalytic reactor that houses catalysts is responsible for facilitating the conversion of impurities, such as tars and pollutants, into more easily handled chemicals. Ensuring the effectiveness of subsequent procedures necessitates the utmost importance of this particular phase.

Step 6: The synthesis of carbon nanomaterials

The synthesis of carbon nanomaterials is a significant area of research in materials science. During this stage, the purified syngas are directed into a CVD reactor, sometimes called the APCVD reactor. The syngas undergoes decomposition at elevated temperatures within the CVD reactor, resulting in the deposition of carbon atoms onto a substrate. The substrate can function as either a catalyst or a specialized substance intended to facilitate the development of 3DGB structures.

Step 7: The formation of 3DGB

The accumulation of carbon atoms on the substrate leads to the formation of linked graphene sheets, developing a three-dimensional graphene foam structure. This foam structure's porosity and surface area features may be customized to meet individual requirements.

Step 8: The process of 3DGB harvesting and post-processing

Upon the completion of the formation of the 3DGB structure, it may be extracted from the substrate. Additional treatments, such as thermal annealing or chemical processes, can be employed to improve the characteristics of the 3DGB and eliminate any residual impurities.

Step 9: The Utilization of 3DGB

The 3DGB that has been formed has the potential to be utilized in a wide range of applications, contingent upon its specific features and intended purpose. Possible applications encompass a wide range of areas, including but not limited to energy storage systems, catalyst support materials, sensor technologies, and several other potential uses.

As mentioned above, the procedure encompasses integrating fast pyrolysis, biomass gasification, syngas purification, and chemical vapor deposition methodologies to transform biomass waste into useful 3DGB nanomaterials. The catalytic purification process is of utmost importance in guaranteeing the high quality of the syngas for synthesizing carbon nanomaterials.

## Results and Discussion

Using biomass pyrolysis to generate green carbon nanoparticles for biofuel and bioenergy production is a novel and environmentally conscious strategy that capitalizes on renewable biomass resources to yield concomitantly carbon nanomaterials (3DGB) and RERs.

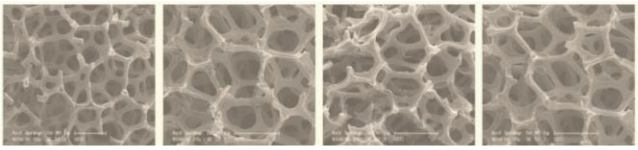

Figure 2: SEM images of 3DGBs generated from BP-GGCN from biomass waste (scale: 500µm)

Fig. 2 illustrates the Scanning Electron Microscopy (SEM) pictures of the 3DGB formed using BP-GGCN derived from biomass waste. SEM was employed to investigate the surface morphology of the 3DGBs. Fig. 2 demonstrates a three-dimensional network that remained intact and free from cracks or collapse following the etching procedure. The skeletal structure of the 3DGB exhibited a hollow configuration, with the skeleton's surface displaying preserved ripples and wrinkles.

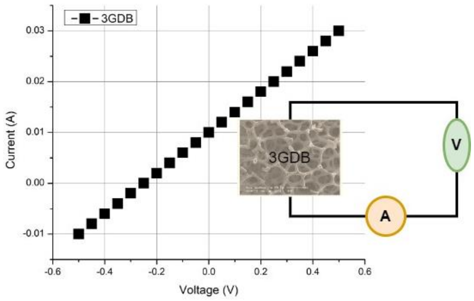


Figure 3: Voltage-Current characteristics of the 3DGB generated using BP-GGCN.

Fig. 3 shows the Voltage-Current characteristics of the 3DGB generated using BP-GGCN. The electrical resistance of the 3DGFs in their initial state was measured to evaluate their electrical transport capabilities. The conductivity (C) of the 3DGB is 7.4 S/m based on the analysis of the I-V curve depicted in Fig. 3. The C value of graphene mixtures surpasses other nanocarbon materials. Nevertheless, the conductivity of the 3DGB material was found to be inferior compared to the conductivity shown by the sample synthesized using CVD of methane. The observed outcome may be ascribed to the disparity in the porosity of the graphene layer and its substrate, namely nickel foam. This observation underscores the potential use of biomass-based 3DGBs as thin conducting substances. The conductivity of the 3DGB has been investigated through experimentation conducted at different temperature levels to have a deeper understanding.

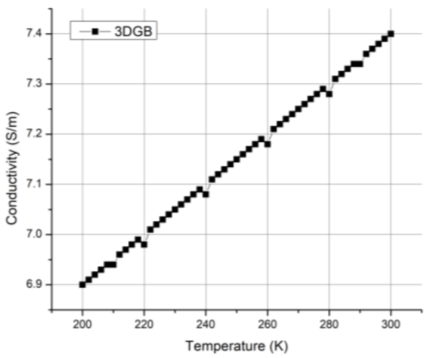


Figure 4: Electrical conductivity of 3DGB generated using BP-GGCN for varying temperatures.

Fig. 4 shows the electrical conductivity of 3DGB generated using BP-GGCN for varying temperatures. According to Fig. 4, the electrical conductivity of the 3DGB material exhibited a rise from 6.9 S/m at a temperature of 200K to 7.4 S/m at a temperature of 300K. This observation serves as evidence for the semi-conducting characteristics of the

3DGB material. The outcome suggests that the 3DGB exhibited a consistent electronic transport characteristic when subjected to low temperatures.

Fig. 5 shows the environmental impacts of the traditional and pyrolysis techniques for producing 3DGBs. With the depletion of fossil resources, ensuring an environmentally friendly future for energy demand has drawn more attention internationally. There have been significant attempts to investigate biomass conversion and usage techniques. The use of non-renewable carbon predecessors, such as $CH_4$, reducing gas (H2), and the requirement for elevated temperatures raise the cost and power consumption of the traditional CVD method for synthesizing 3DGBs. In comparison, the pyrolytic approach results in independent 3DGBs with significantly lower prices and energy use from lignin, cellulose, and green biomass wastes like sawdust. The heat created by the carbon predecessors, which are renewable, may be used as a form of energy to make 3DGB.

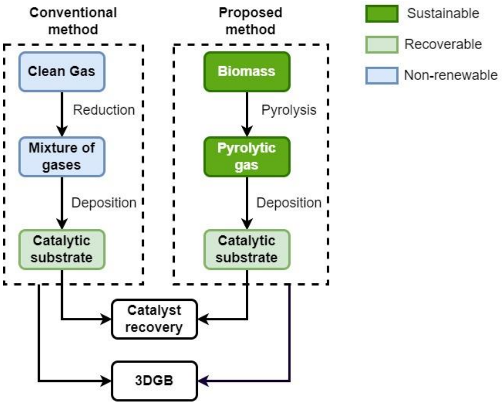


Figure 5: The environmental impacts of the traditional and pyrolysis techniques for producing 3DGBs.

Fig. 6 compares energy demand and total GHG emission for the proposed BP-GGCN and traditional CVD method. The suggested BP-GGCN approach has a sizable environmental and energy efficiency benefit over the conventional CVD method, as shown in Fig. 6. The standard CVD approach generates 36.2 units more total GHG emissions than the suggested method, which emits just 25.6 units. Additionally, compared to the conventional CVD method's much higher 222,587 Joule energy need, the proposed method's energy requirement is noticeably decreased to just 145,587 Joules. Adopting the suggested BP-GGCN approach, which results in reduced GHG emissions and increased energy efficiency, is advantageous from an environmental and energy efficiency standpoint, as shown by the results.

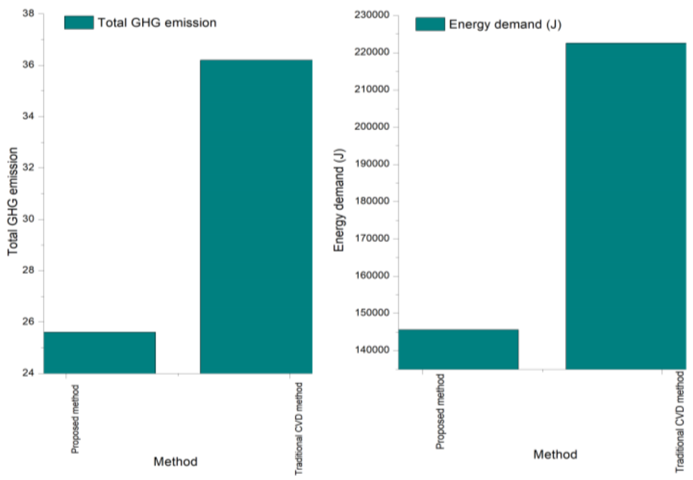


Figure 6: Comparison of energy demand and total GHG emission for the proposed BP-GGCN and traditional CVD method

## Conclusion

The production of biofuels and bioenergy is proposed in this research to use Biomass Pyrolysis to Generate Green Carbon Nanomaterials (BP-GGCN). The recommended approach produces outstanding 3DGBs utilizing leftover pyrolysis gases and thermal waste, maximizing biomass pyrolysis's financial benefits and sustainability. The resulting 3DGBs perform well in applications requiring energy storage and environmental consideration. To examine the surface morphology of the 3DGBs, SEM was used. The 3DGB's skeletal structure had a hollow design, and the skeleton's surface still had wrinkles and ripples. Their initial electrical resistance was evaluated to assess the 3DGFs' capacity for electrical transmission. Based on the examination of the I-V curve, it was discovered that the conductivity (C) of the 3DGB is 7.4 S/m. The results reveal that adopting the proposed BP-GGCN strategy, which leads to lower GHG emissions and higher energy efficiency, is desirable from an environmental and energy efficiency point of view.

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