Sustainability: Theory, Practice and Policy
Volume 1, Issue 2, Desember 2021 (95-232)
ISSN: 2808-4829

Utilization of Biomass as a Carbon Source for The Synthesis of Graphene as a Sustainable Materials Innovation

Dina Rahmawati, Melda Taspika, Nur Afifah Zen

Faculty of Telecommunication and Electrical Enginering

Institut Teknologi Telkom Purwokerto

(email: dinarahma1993@gmail.com)

Abstract

One of the alternative ways to reduce the use of fossil fuels is the advancement of energy storage devices and energy conversion devices for renewable energy. The electrode is an essential part of its electrochemical performance in energy storage. The specific surface area of the electrode will affect the energy density, lifetime, charging, and discharging of the energy storage devices. Graphene has been widely used for energy storage, such as batteries and supercapacitors. Generally, graphene is synthesized from graphite as a carbon source which some researchers have reported. However, they are still fighting against simple synthesis methods, low-cost raw materials, eco-friendly co-product, and large-scale production. Therefore, advanced research is required to bring graphene from laboratory-scale projects to industry. One of the best solutions is biomass as a raw material to replace graphite in synthesizing graphene. In this review, some methods for synthesizing graphene from biomass will explain briefly, following with their strength and weakness.

Keywords:
graphene; biomass; carbon; sustainable materials

Introduction

Biomass has been used for fuel sources, perfume, cosmetics, food additives, nutritional elements, cleaning products, detergent, and plastic because of its abundance, carbon sources, and safety. Lignocellulosic biomass, composed of cellulose, hemicellulose, and lignin, was used to produce biodiesel using oleaginous microbe to collect lipid content of plant (Chintagunta et al. 2021). That could enhance the economic value of agricultural residues as the largest source of lignocellulosic (Yousuf 2012). In addition, the biomass utilization for essential oil is gradually increasing since Lummiss et al. (2012) found a method to assemble complex structures from a molecular structure in plant materials for the first time. The essential oil was widely used for perfume, cosmetics, and aromatherapy (Lummiss et al. 2012). The use of microalgae biomass (*Chlorella sorokiniana*) as a food additive in pasta recipes could exchange synthetic dye. The addition of microalgae to pasta could enhance polyunsaturated fatty acid, chlorophyll, and carotenoid content, potentially preventing foodborne diseases (Bazarnova et al. 2021). Besides, household organic waste like fruit peels and vegetable dregs could be chemically treated to form eco-enzyme for cleaning products such as detergent, kitchen cleaner, and floor cleaner (Mavani et al. 2020). Moreover, biodegradable plastic (bioplastic) could be made from biomass such as algae and rice straw as a carbon source, potentially decreasing environmental pollutants and opening the opportunity to advance sustainable packaging products (Coppola et al. 2021).

Graphene is a two-dimensional (2D) carbon allotrope that possesses sp^2 carbon hybridization (Novoselov et al. 2004) with a hexagonal lattice and has a thickness of one atom (Novoselov et al. 2012). Graphene is the basic structure that forms other allotropes of carbon, such as fullerenes, nanotubes, and graphite. Zero dimension (0D) fullerene is a structure formed when graphene is rolled into a ball, 2D nanotubes are produced by rolling graphene into a tube, and 3D graphite is formed from graphene stacks or arrangements to produce a 3-dimensional shape. Graphene material has attracted many researchers' attention because of its fascinating electronic, thermal, and mechanical properties (Mu et al. 2014). Graphene has great potential for various applications such as transparent electrodes, flexible displays, energy storages (batteries, capacitors, and fuel cells), sensors, biosensors, biomedical, and energy generation. Among the superior properties of graphene include excellent thermal conductivity (5×10^3 $W.m^{-}1.K^{-1}$), high electrical conductivity reaching (6×10^3 $S.cm^{-1}$), high charge carrier mobility at room temperature (2.5×10^5 $cm^2.V^{-1}.s^{-1}$), and large theoretical surface area (2.63×10^3 $m^2.g^{-1}$) (Troncoso and Torres 2020).

In general, graphene is synthesized from graphite as a carbon source. Various methods of synthesizing graphene from graphite include the mechanical exfoliation graphene (Scotch-tape) method (Novoselov et al. 2012), chemical vapor decomposition (CVD) (M. Wang et al. 2015), epitaxial growth on SiC substrate (Whitener and Sheehan 2014), and reduction graphene oxide (RGO) (Husnah et al. 2017) (Dreyer et al. 2010). The mechanical exfoliation method was used to synthesize graphene by Geim and Novoselov. This method is carried out by peeling off crystalline graphite or carbon layers to the micrometer scale using a stylus. One graphene sheet was observed hanging on a silicon oxide substrate with an optical microscope, this method can produce graphene with good quality, but the results obtained have a low quantity (Novoselov et al. 2004) (Novoselov et al. 2012). The CVD method is a graphene synthesis method using SiO_2 substrate as a medium for the growth of carbon atoms into graphene. This method can produce graphene in large quantities but requires relatively expensive costs due to it is needed supporting equipment with high technology. Epitaxial growth method growth on SiC substrate also requires relatively expensive fabrication costs because this method requires high vacuum conditions (Berger et al. 2004).

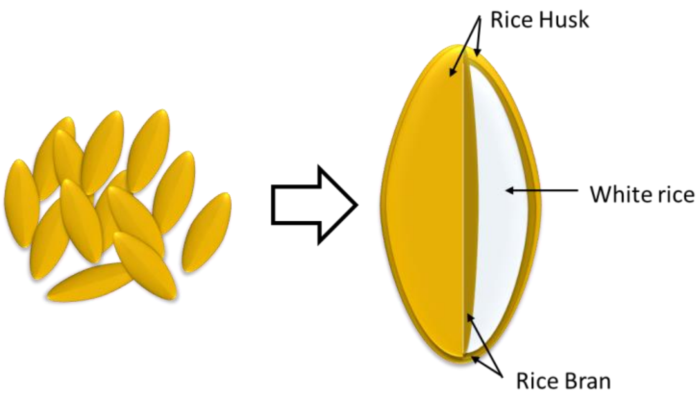
Another synthesis method developed is RGO (Stankovich et al. 2007). This method synthesizes graphite into graphite oxide by involving several chemicals, namely concentrated acids such as sulfuric acid, nitric acid, and phosphoric acid, then oxidation of graphite to graphene oxide (GO) using powerful oxidizing reagents such as potassium permanganate and potassium perchlorate. The final step is that the oxide bond in GO is reduced by using chemical or thermal reducing agents (Nekahi, Marashi, and Haghshenas 2014) (Chua and Pumera 2014). Chemical reducing agents involve chemicals such as hydrazine, sodium borohydride, hydroxylamine, glucose, hydroquinone, and L-ascorbic acid. Thermal reducing agents involve heating processes such as the furnace, microwave, or hydrothermal. The graphene oxide reduction method based on graphite requires several complicated steps, a variety of chemicals, and a long synthesis time.

Therefore, a simple method made from cheap, environmentally friendly raw materials can be produced on a large scale, and sustainable development is still a challenge. Recently, activated carbon from biomass is one of the materials with high potential as a carbon source to replace graphite in graphene synthesis. Biomass is organic material that usually comes from plants or their derivatives, such as wood, wood waste, crops, agricultural production waste, etc. The use of biomass as a carbon source has several advantages, including cost-effectiveness because it is cheap and abundant, environmentally friendly, can be produced on a large scale, and is a sustainable and renewable material (Ouyang et al. 2021) (Saha and Dutta 2021) (Raghavan, Thangavel, and Venugopal 2017) (Yang Liu et al. 2018). This brief review presents several preparation processes for synthesizing graphene from biomass, including mechanisms, methods, and applications.

Graphene from rice husk

Rice husk is a by-product of rice generated during milling, the outer hard protective layer of rice grain (shown in Figure 1). About 20% of the rice weight is received as a husk during rice milling. The world annual production of rice husk is about 120 million tons (Tuck et al. 2012), and it is estimated to increase each year along with the increasing quantities of rice processing, impacting environmental problems (Safian, Umar, and Mohamad Ibrahim 2021). Recently, many researchers have developed the use of rice husks as a carbon source for the synthesis of graphene (Muramatsu et al. 2014) (Seitzhanova et al. 2018) (Sankar et al. 2017) to reduce environmental problems and increase the economic value of rice husks. Rice husk contains chemical compounds that can be used as a carbon source to synthesize graphene. Recently, rice husk has become the interest of many researchers because it contains chemical compounds that can be used as a carbon source to synthesize graphene. Chemical compounds in rice husk consist of 50% cellulose, 30% lignin, and 20% silica (Seitzhanova et al. 2018). Cellulose and hemicellulose or lignin content are the main compounds for activating carbon, while the silica content is a constituent of impurities in the synthesis of graphene; to remove it requires pre-treatment using an alkaline solution.

Figure 1. A basic illustration of rice husk



In general, the synthesis of graphene from biomass sources is carried out in several processes, specifically carbonization, graphitization, and activation. Carbonization is the process of increasing the carbon content through thermal treatment to remove low molecular weight compounds. In other terms, carbonization is often associated with adjusting the carbon structure. Graphitization is related to arranging the structure of carbon into a graphite-like structure, usually employing further thermal treatment after carbonization. Activation is a process to remove impurity compounds that coat the carbon surface to open or increase the porosity of activated carbon and increase the diameter of the pores that have been formed in the carbonization process. The activation process can be done chemically, physically, or by combining the two. Chemical activation is carried out using chemical materials such as KOH, H_2SO_4, NaOH, NaCl, and others (Stojanovska et al. 2019) (Yan Liu et al. 2012), while the physical activation method can be through heat treatment.

Muramatsu et al. (2014) have first reported the synthesis of graphene from rice husk as a carbon source using potassium hydroxide (KOH). The main processes used in this experiment are carbonization for conversion of rice husk (biomass source) to rice husk ash (RHA), chemical activation using KOH to transform RHA into graphene-based structures. Then the mixture of RHA with KOH was heat treated. During the synthesis process, the mixture of RHA with KOH is entered in a container coated with carbon black to protect against oxidation against air. Activation of RHA using KOH can result in high-purity graphene formation, producing graphene with an enriched edge structure, clean, stable, and atomically smooth edges. The resulting graphene has the potential as a high-performance carbon-based energy storage fabricating and conversion device (e.g., supercapacitors and hydrogen storage systems), next-generation water filters, and various nanocomposites.

Rhee et al. (2015) also used KOH as a chemical activation reagent to synthesize graphene from rice husks. The use of KOH as the activation reagent involves a redox reaction between carbon (C) and KOH, which influences the morphology of the generated graphene, expands the lattice spacing, increases the specific surface area of graphene, and promotes the formation of a porous structure. However, the interaction of C with KOH can produce inorganic impurities, accordingly that further purification is needed to remove potassium metal from graphene (Liou and Wang 2020). The purification process can be carried out by washing the activated carbon using hydrogen peroxide (H_2O_2) and deionized (DI) water (Rhee et al. 2015). Singh et al. (2017) have modified the synthesis process Muramatsu et al. (2014). The modification was carried out by replacing carbon black with rice husk (Singh, Bahadur, and Pal 2017). Modifications have been reported to replace carbon black with rice husk itself, making graphene synthesis more cost-effective.

As shown in some of the literature above, it can be concluded that the synthesis of graphene using rice husks as raw material is possible. In addition, because it involves a simple process and is cost-effective, this approach can be applied in synthesizing graphene in large quantities. Moreover, the synthesis of graphene from rice husks can be applied in various applications in the field of civil engineering (such as cementitious construction materials) (Rhee et al. 2015), transistors, lithium batteries (Liang et al. 2017; Xue et al. 2021), and supercapacitors (Liang et al. 2017). Among the applications mentioned, supercapacitors are considered to be one of the most appropriate uses for graphene derived from rice husks. Sankar et al. (2017) have succeeded in synthesizing graphene nanosheets using the carbonization method followed by an activation process using one-stage KOH for supercapacitor electrodes (Sankar et al. 2017). The resulting graphene nanosheet has a higher surface area than the previous literature.

Graphene from rice straw

The Rice straw is a by-product of rice produced during the harvesting process. About 50 - 60% of the rice itself is straw. The amount of rice straw will increase along with the increase in rice production (Rezania et al. 2017). In general, rice straw is used as animal feed, fertilizer, compost, packaging material, and paper material, but most of it is burned in open fields for quick disposal purposes (Nam et al. 2018). This contributes to environmental problems and global warming (Jorn-am et al. 2021). Various strategies continue to be developed to increase the utilization of this type of biomass. Like rice husks, rice straw contains various compounds including cellulose, hemicellulose, and lignin which can also be used as a carbon source for the synthesis of graphene (Xu et al. 2020). The utilization of rice straw as a carbon source has been developed by many researchers (Sudhan et al. 2017). Suzuki et al. (2007) studied the use of rice straw as a carbon source. The results confirm that rice straw is a very potential material economically (Jin et al. 2018; Suzuki et al. 2007; Zhu et al. 2017).

Adinaveen et al. (2015) have reported the results of the synthesis of activated carbon from rice straw. A two-stage process namely carbonization followed by activation using phosphoric acid (H3PO4), generates morphological characteristics that lead to porous activated carbon, high surface area, and good electrochemical properties. These results are promising for high-performance supercapacitor applications (Adinaveen et al. 2015). Saad et al. (2019), have produced carbon from rice straw by carbonization and KOH activation. Variations of heat treatment produce activated carbon properties similar to graphite in graphene sheets. The resulting surface area increases with the increase in activation temperature (Saad et al. 2019). Recently, Charoensook et al. (2021) have produced activated carbon from rice straw with a specific surface area and high specific capacity for energy storage applications. Activated carbon with these specifications is produced through a process of carbonization, activation using KOH and nitrogen doping treatment (Charoensook et al. 2021). Based on the literature review, it is evident that rice straw has great potential for various applications, especially in supercapacitor applications. Further development of methods is still needed to obtain high quality carbon from rice straw.

Graphene from coconut shell

The coconut shell is part of the coconut fruit covered by coconut husk, which is endocarp-shaped and hard. The coconut shell is a protective layer between the coconut flesh and coconut husk (Sahat 2017). Coconut shell is considered a waste with low economic value, and their utilization is not yet optimal. Generally, coconut shell is used as a single-use fuel. Therefore, it is necessary to increase the utilization of coconut shell waste to increase its economic value. Coconut shell contains chemical compounds including cellulose (34%), hemicellulose (21%), and lignin (27%) which are composed of carbon elements (74.3%) (Bledzki, Mamun, and Volk 2010; Liyanage and Pieris 2015; Sekhon, Kaur, and Park 2021).

Cellulose is an organic compound with the formula $(C_6H_{10}O_5)_n$, which is found in cell walls and strengthens the structure. Hemicellulose is a heterogeneous polysaccharide polymer that fills the space between cellulose fibers in plant cell walls, a filler matrix for cellulose fibers, or a filler matrix for cellulose fibers. Another component is lignin, which binds to other cells and provides strength. Cellulose, hemicellulose, and lignin significantly affect the content of the carbon phase formed (Bledzki, Mamun, and Volk 2010; Z. Wang et al. 2018). Sources of biomass containing these compounds can be used as a carbon source in the synthesis of graphene.

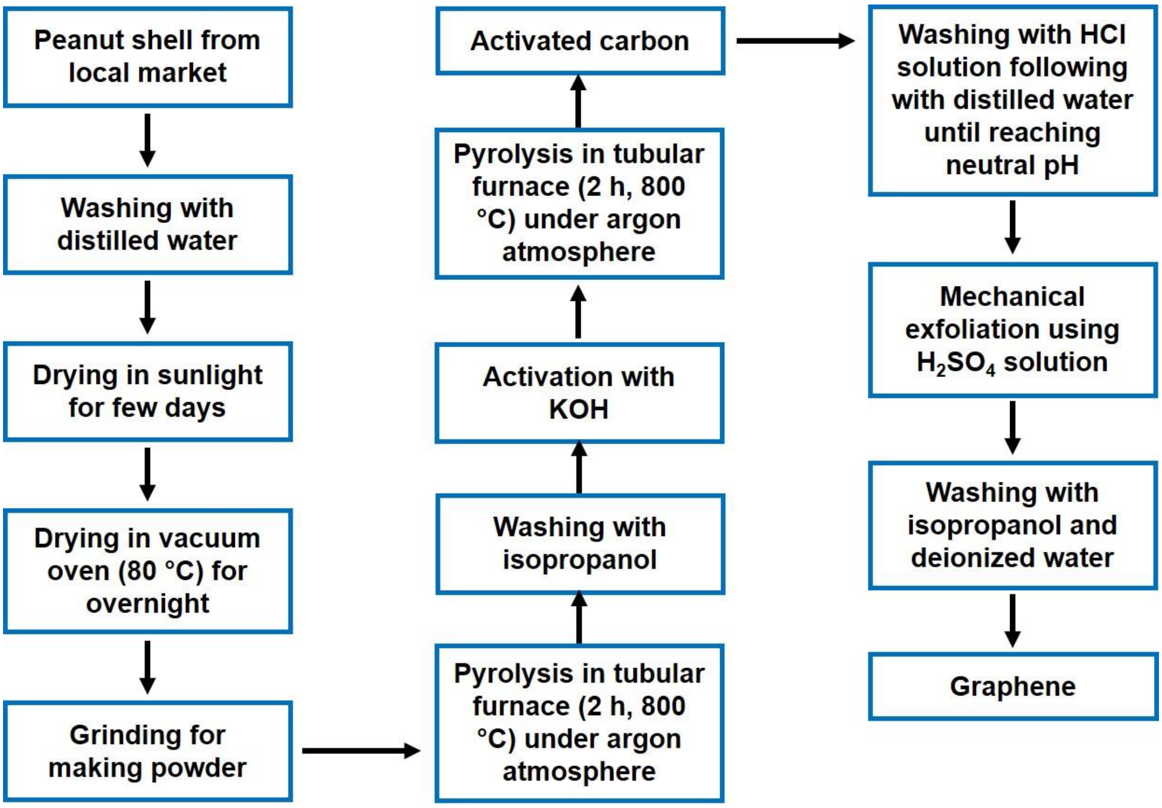
Carbon materials from coconut shells have been studied for their capabilities as electrodes for supercapacitor applications. Yan et al. (2010) showed that activated carbon from coconut shells has a high surface area and pore surface (Geng et al. 2013; Yang et al. 2010). Many researchers have carried out the synthesis of graphene from coconut shells (Baqiya et al. 2020). Wachid et al. 2014 used a simple, easy and inexpensive method. The method used is carbonization and activation. Dehydration, cellulose evaporation, lignin evaporation, and carbon purification were employed in the coconut shell during the carbonization process (Wachid et al. 2014). Coconut shells that have become charcoal will produce carbon by 57.11%, oxygen by 42.67%, and other materials by 0.23% (Mozammel, Masahiro, and Bhattacharya 2002). In another study, coconut shell was used as a carbon source to synthesize reduced graphene oxide (rGO) (Asih et al. 2019; Darminto et al. 2018; Kurniasari et al. 2017; Prasetya et al. 2015; Yang et al. 2010).

Graphite can be classified into natural graphite and synthetic graphite, produced from the graphitization process (Simón et al. 2018). In general, rGO produced from coconut shell combustion has characteristics equivalent to natural graphite rGO (Somanathan et al. 2015). Nugraheni (2017) has reported the results of the characterization showing that coconut shell that has become charcoal will produce a reduced graphene oxide phase (Nugraheni et al. 2017). Sujiono et al. (2020) have reported the synthesis of graphene from coconut shells as a carbon source to replace natural graphite (Sujiono et al. 2020). Graphite powder from coconut shell was converted to graphene oxide (GO) using the Hummers method, and the resulting GO tends to form an rGO phase. This method involves several materials such as $NaNO_3$, H_2SO_4, $KMNO_4$ (Sujiono et al. 2020). However, $NaNO_3$ will produce toxic gases NO_2 and N_2O_4, released during the oxidation process. Therefore, the opportunity to develop a coconut shell-based graphene synthesis method is still very much needed.

Graphene from peanut shell

Generally, peanut shell is only used for animal feed and building material. The addition of peanut shells to the plaster could reduce thermal conductivity, which enabled the mixture to be an insulator (Lamrani et al. 2017). Recently, peanut shells have significantly increased as a raw material in synthesizing carbon-based materials. Bay et al. (2020) prepared porous biomass charcoal from peanut shells without using chemical activator and protective gases during the pyrolysis process in the furnace. The as-produced porous biomass charcoal could adsorb Pb^{2+} and methylene blue in wastewater (Bai et al. 2020). Peanut shell was used as a raw material to synthesize mesoporous few-layer graphene nanosheets via mechanical exfoliation to apply for binder-free supercapacitor electrodes. The synthesis procedures are represented in Figure 2. The as-produced graphene provided a high specific surface area (2070 m^2/g) with a large pore volume (1.33 cm^3/g). The capacitor capacity reached 186 F/g with the highest energy density, and the highest power density is 58.125 Wh/kg and 37.5 W/kg, respectively (Purkait et al. 2017). Mechanical exfoliation is a top-down technique that provides advantages such as simple methods and producing high-purity graphene without defects. However, this method is unaffordable for large-scale graphene synthesis (Bhuyan et al. 2016). Another disadvantage of using the mechanical exfoliation method is reducing graphene lateral size, which decreases its surface area due to the exerted force during the exfoliation process (Yi and Shen 2015).

Figure 2. The activated carbon synthesis procedure from peanut shells with KOH as an activator agent (Purkait et al. 2017).



Activated carbon is a basis in graphene synthesizing, so that is important to observe its synthesis methods. Different activator agents would produce different structures of the as-produced activated carbon. The surface structure of activated carbon will affect the absorption capacity of the as-produced materials. Guo et al. (2018) has prepared activated carbon from peanut shell using one-step synthesis with $ZnCl_2$, $FeCl_3$, and their mixture as the chemical activator. The synthesis procedures are explicitly described in Figure 4. The agent activator ratio of Fe/Zn was varied and contributed to the specific area surface of activated carbon. This material could be applied for electrodes because it has a large surface area (1482 m^2/g) and abundant micropores (Guo et al. 2019). Zhang et al. (2015) has synthesized magnetic activated carbon from peanut shells via a one-step method using K_2CO_3 as activator agent and Fe_3O_4 as a magnetic additive agent, presented in Figure 5. The structures and the properties of the as-produced activated carbon depended on the activation temperature and activation time. The maximum specific surface area (1219 and 1236 m^2/g) could be reached by the samples activated at 750 and 800 °C for 1.5 and 1 hour, respectively. Activation time facilitated the porosity development of the sample (micropore, mesopore, or macropore). (Zhang et al. 2015).

Figure 3. The activated carbon synthesis procedure from peanut shells uses $ZnCl_2$, $FeCl_3$, or Fe/Zn as an activator agent (Guo et al. 2019).

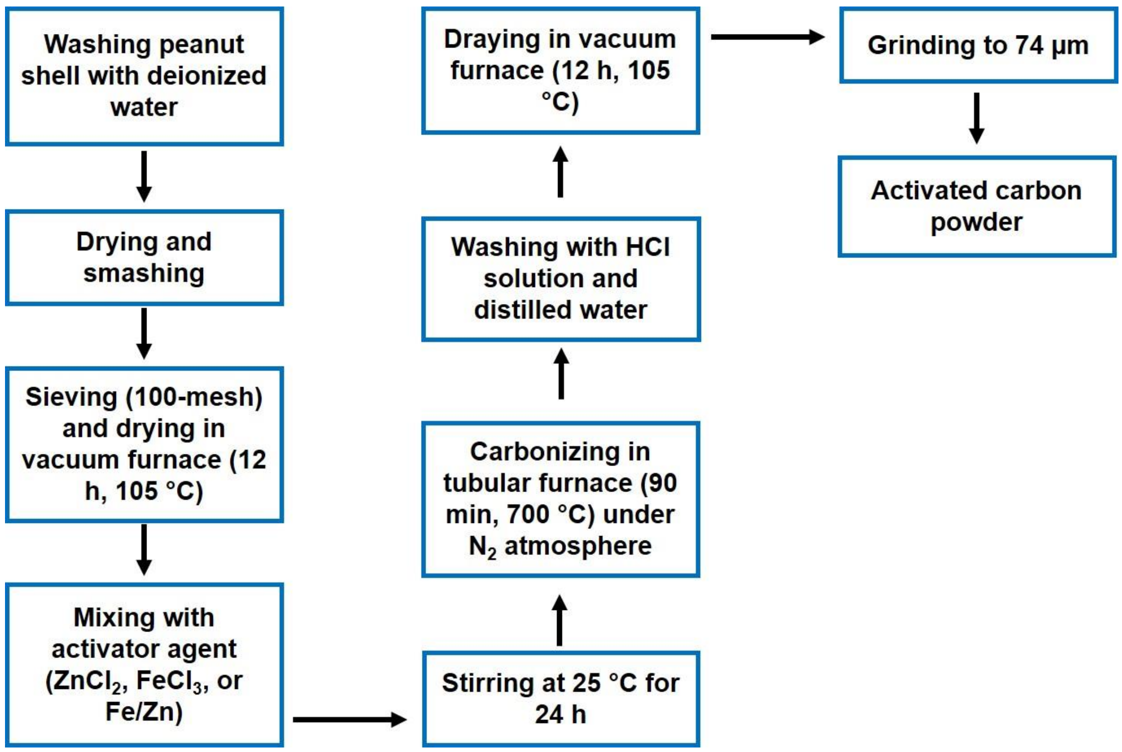
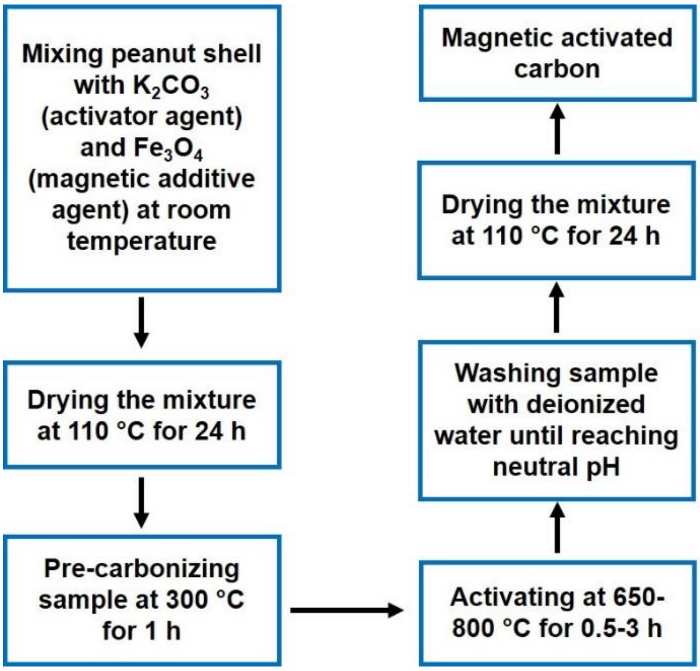


Figure 4. The magnetic-activated carbon synthesis procedure from peanut shells with K_2CO_3 as an activator agent (Zhang et al. 2015).



Conclusions

This brief review summarizes the utilization of biomass as a carbon source in graphene synthesis. The sources and synthesis methods of biomasses have been discussed for sustainable energy storages such as a capacitor, supercapacitor, and battery electrode. The as-produced graphene and its fullerenes depend on the biomass chemical and its synthesis method. All methods discussed above have several advantages, such as simple methods and low-cost production, enabling them to be used in large-scale production. However, advancement is still required in producing high-quality graphene.

References

Asih, Retno et al. 2019. "Comparative Study on Magnetism of Reduced Graphene Oxide (Rgo) Prepared from Coconut Shells and the Commercial Product." *Materials Science Forum* 966 MSF: 290–95.

Bai, Suzhen et al. 2020. "Facile Preparation of Porous Biomass Charcoal from Peanut Shell as Adsorbent." *Scientific Reports* 10(1): 1–9.

Bazarnova, Julia et al. 2021. "Use of Microalgae Biomass for Fortification of Food Products from

Grain."

Bhuyan, Md. Sajibul Alam et al. 2016. "Synthesis of Graphene." *International Nano Letters* 6(2): 65–83.

Chintagunta, Anjani Devi et al. 2021. "Biodiesel Production From Lignocellulosic Biomass Using Oleaginous Microbes: Prospects for Integrated Biofuel Production." *Frontiers in Microbiology* 12(August): 1–23.

Chua, Chun Kiang, and Martin Pumera. 2014. "Chemical Reduction of Graphene Oxide: A Synthetic Chemistry Viewpoint." *Chemical Society Reviews* 43(1): 291–312.

Coppola, Gerardo et al. 2021. "Bioplastic from Renewable Biomass: A Facile Solution for a Greener Environment." *Earth Systems and Environment* 5(2): 231–51.

Darminto et al. 2018. "Enhanced Magnetism by Temperature Induced Defects in Reduced Graphene Oxide Prepared from Coconut Shells." *IEEE Transactions on Magnetics* 54(10): 1–5.

Dreyer, Daniel R., Sungjin Park, Christopher W. Bielawski, and Rodney S. Ruoff. 2010. "The Chemistry of Graphene Oxide." *Chemical Society Reviews* 39(1): 228–40.

Husnah, Miftahul et al. 2017. "A Modified Marcano Method for Improving Electrical Properties of Reduced Graphene Oxide (RGO)." *Materials Research Express* 4(6).

Kurniasari et al. 2017. "Defect and Magnetic Properties of Reduced Graphene Oxide Prepared from Old Coconut Shell." *IOP Conference Series: Materials Science and Engineering* 196(1).

Lamrani, M. et al. 2017. "Experimental Study of Thermal Properties of a New Ecological Building Material Based on Peanut Shells and Plaster." *Case Studies in Construction Materials* 7(July): 294–304.

Liang, Yeru et al. 2017. "Facile Synthesis of Highly Porous Carbon from Rice Husk." *ACS Sustainable Chemistry and Engineering* 5(8): 7111–17.

Liu, Yang et al. 2018. "Design and Preparation of Biomass-Derived Carbon Materials for Supercapacitors: A Review." *C* 4(4): 53.

Liyanage, Chinthani D., and Mevan Pieris. 2015. "A Physico-Chemical Analysis of Coconut Shell Powder." *Procedia Chemistry* 16: 222–28.

Mozammel, Hoque M., Ota Masahiro, and S. C. Bhattacharya. 2002. "Activated Charcoal from Coconut Shell Using ZnCl2 Activation." *Biomass and Bioenergy* 22(5): 397–400.

Mu, Xin et al. 2014. “Thermal Transport in Graphene Oxide - From Ballistic Extreme to Amorphous Limit.” *Scientific Reports* 4(Md): 1–9.

Muramatsu, Hiroyuki et al. 2014. “Rice Husk-Derived Graphene with Nano-Sized Domains and Clean Edges.” *Small* 10(14): 2766–70.

Novoselov, K. S. et al. 2004. “Electric Field in Atomically Thin Carbon Films.” *Science* 306(5696): 666–69.

Nugraheni, Ananda Yogi et al. 2017. “Structural Analysis on Reduced Graphene Oxide Prepared from Old Coconut Shell by Synchrotron X-Ray Scattering.” *IOP Conference Series: Materials Science and Engineering* 196(1).

Prasetya, Fandi Angga, M. Nasrullah, Ananda Yogi Nugraheni, and Darminto. 2015. “Study of Raman Spectroscopy on Graphene Phase from Heat Treatment of Coconut (Cocus Nucifera) Shell.” *Materials Science Forum* 827: 290–93.

Purkait, Taniya et al. 2017. “Large Area Few-Layer Graphene with Scalable Preparation from Waste Biomass for High-Performance Supercapacitor.” *Scientific Reports* 7(1): 1–14.

Saad, Mohamad Jani et al. 2019. “Physical and Chemical Properties of the Rice Straw Activated Carbon Produced from Carbonization and KOH Activation Processes.” *Sains Malaysiana* 48(2): 385–91.

Sahat, Sisca Fibriliani. 2017. “Introducing Indonesian Various Coconut Products.” *Export News Indonesia* (February): 1–12.

Seitzhanova, Makpal et al. 2018. “Synthesis and Characterization of Graphene Layers from Rice Husks.” *Chemical Bulletin of Kazakh National University* (2): 12–18.

Simón, María et al. 2018. “Untreated Natural Graphite as a Graphene Source for High-Performance Li-Ion Batteries.” *Batteries* 4(1): 1–9.

Singh, Pushpendra, Jitendra Bahadur, and Kaushik Pal. 2017. “One-Step One Chemical Synthesis Process of Graphene from Rice Husk for Energy Storage Applications.” *Graphene* 06(03): 61–71.

Somanathan, Thirunavukkarasu et al. 2015. “Graphene Oxide Synthesis from Agro Waste.” *Nanomaterials* 5(2): 826–34.

Stankovich, Sasha et al. 2007. “Synthesis of Graphene-Based Nanosheets via Chemical Reduction of Exfoliated Graphite Oxide.” *Carbon* 45(7): 1558–65.

Sudhan, N. et al. 2017. "Biomass-Derived Activated Porous Carbon from Rice Straw for a High-Energy Symmetric Supercapacitor in Aqueous and Nonaqueous Electrolytes." *Energy and Fuels* 31(1): 977–85.

Suzuki, R. M., A. D. Andrade, J. C. Sousa, and M. C. Rollemberg. 2007. "Preparation and Characterization of Activated Carbon from Rice Bran." *Bioresource Technology* 98(10): 1985–91.

Troncoso, Omar P, and Fernando G Torres. 2020. "Bacterial Cellulose — Graphene Based Nanocomposites." (Table 1): 1–17.

Tuck, Christopher O. et al. 2012. "Valorization of Biomass: Deriving More Value from Waste." *Science* 337(6095): 695–99.

Wachid, Frischa M. et al. 2014. "Synthesis and Characterization of Nanocrystalline Graphite from Coconut Shell with Heating Process." *AIP Conference Proceedings* 1586: 202–6.

Wang, Zhanghong, Dekui Shen, Chunfei Wu, and Sai Gu. 2018. "State-of-the-Art on the Production and Application of Carbon Nanomaterials from Biomass." *Green Chemistry* 20(22): 5031–57.

Xu, Zenghua et al. 2020. "Green Synthesis of Nitrogen-Doped Porous Carbon Derived from Rice Straw for High-Performance Supercapacitor Application." *Energy and Fuels* 34(7): 8966–76.

Yousuf, Abu. 2012. "Biodiesel from Lignocellulosic Biomass - Prospects and Challenges." *Waste Management* 32(11): 2061–67.

Zhang, Shengli et al. 2015. "Single-Step Synthesis of Magnetic Activated Carbon from Peanut Shell." *Materials Letters* 157: 281–84.

Journal article on website

Adinaveen, T., L. John Kennedy, J. Judith Vijaya, and G. Sekaran. 2015. "Surface and Porous Characterization of Activated Carbon Prepared from Pyrolysis of Biomass (Rice Straw) by Two-Stage Procedure and Its Applications in Supercapacitor Electrodes." *Journal of Material Cycles and Waste Management* 17(4): 736–47.

Berger, Claire et al. 2004. "Ultrathin Epitaxial Graphite: 2D Electron Gas Properties and a Route toward Graphene-Based Nanoelectronics." *Journal of Physical Chemistry B* 108(52): 19912–

16.

Charoensook, Kanruethai et al. 2021. "Preparation of Porous Nitrogen-Doped Activated Carbon Derived from Rice Straw for High-Performance Supercapacitor Application." *Journal of the Taiwan Institute of Chemical Engineers* 120: 246–56.

Guo, Feiqiang et al. 2019. "Carbon Electrode Material from Peanut Shell by One-Step Synthesis for High Performance Supercapacitor." *Journal of Materials Science: Materials in Electronics* 30(1): 914–25.

Lummiss, Justin A.M. et al. 2012. "Chemical Plants: High-Value Molecules from Essential Oils." *Journal of the American Chemical Society* 134(46): 18889–91.

Mavani, Hetal Ashvin Kumar et al. 2020. "Antimicrobial Efficacy of Fruit Peels Eco-Enzyme against Enterococcus Faecalis: An in Vitro Study." *International Journal of Environmental Research and Public Health* 17(14): 1–12.

Sankar, S. et al. 2017. "Ultrathin Graphene Nanosheets Derived from Rice Husks for Sustainable Supercapacitor Electrodes." *New Journal of Chemistry* 41(22): 13792–97.

Yi, Min, and Zhigang Shen. 2015. "A Review on Mechanical Exfoliation for the Scalable Production of Graphene." *Journal of Materials Chemistry A* 3(22): 11700–715.

Journal article with DOI

Baqiya, Malik Anjelh et al. 2020. "Structural Study on Graphene-Based Particles Prepared from Old Coconut Shell by Acid–Assisted Mechanical Exfoliation." *Advanced Powder Technology* 31(5): 2072–78. https://doi.org/10.1016/j.apt.2020.02.039.

Bledzki, Andrzej K., Abdullah A. Mamun, and Jürgen Volk. 2010. "Barley Husk and Coconut Shell Reinforced Polypropylene Composites: The Effect of Fibre Physical, Chemical and Surface Properties." *Composites Science and Technology* 70(5): 840–46. http://dx.doi.org/10.1016/j.compscitech.2010.01.022.

Geng, Xin et al. 2013. "Influence of Reactivation on the Electrochemical Performances of Activated Carbon Based on Coconut Shell." *Journal of Environmental Sciences (China)* 25(S1): S110–17. http://dx.doi.org/10.1016/S1001-0742(14)60638-0.

Jin, Hong et al. 2018. "Three-Dimensional Interconnected Porous Graphitic Carbon Derived from Rice Straw for High Performance Supercapacitors." *Journal of Power Sources*

384(November 2017): 270–77. https://doi.org/10.1016/j.jpowsour.2018.02.089.

Jorn-am, Thanapat et al. 2021. "Quasi-Solid, Bio-Renewable Supercapacitor with High Specific Capacitance and Energy Density Based on Rice Electrolytes and Rice Straw-Derived Carbon Dots as Novel Electrolyte Additives." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 628(June): 127239. https://doi.org/10.1016/j.colsurfa.2021.127239.

Liou, Tzong Horng, and Pie Ying Wang. 2020. "Utilization of Rice Husk Wastes in Synthesis of Graphene Oxide-Based Carbonaceous Nanocomposites." *Waste Management* 108: 51–61. https://doi.org/10.1016/j.wasman.2020.04.029.

Liu, Yan et al. 2012. "Simultaneous Preparation of Silica and Activated Carbon from Rice Husk Ash." *Journal of Cleaner Production* 32: 204–9. http://dx.doi.org/10.1016/j.jclepro.2012.03.021.

Nam, Hyungseok, Woongchul Choi, Divine A. Genuino, and Sergio C. Capareda. 2018. "Development of Rice Straw Activated Carbon and Its Utilizations." *Journal of Environmental Chemical Engineering* 6(4): 5221–29. https://doi.org/10.1016/j.jece.2018.07.045.

Nekahi, A., P. H. Marashi, and D. Haghshenas. 2014. "Transparent Conductive Thin Film of Ultra Large Reduced Graphene Oxide Monolayers." *Applied Surface Science* 295: 59–65. http://dx.doi.org/10.1016/j.apsusc.2014.01.004.

Novoselov, K. S. et al. 2012. "A Roadmap for Graphene." *Nature* 490(7419): 192–200. http://dx.doi.org/10.1038/nature11458.

Ouyang, Dan-dan et al. 2021. "A Review of Biomass-Derived Graphene and Graphene-like Carbons for Electrochemical Energy Storage and Conversion." *New Carbon Materials* 36(2): 350–72. http://dx.doi.org/10.1016/S1872-5805(21)60024-0.

Raghavan, Nivea, Sakthivel Thangavel, and Gunasekaran Venugopal. 2017. "A Short Review on Preparation of Graphene from Waste and Bioprecursors." *Applied Materials Today* 7: 246–54. http://dx.doi.org/10.1016/j.apmt.2017.04.005.

Rezania, Shahabaldin et al. 2017. "Review on Fermentative Biohydrogen Production from Water Hyacinth, Wheat Straw and Rice Straw with Focus on Recent Perspectives." *International Journal of Hydrogen Energy* 42(33): 20955–69. http://dx.doi.org/10.1016/j.ijhydene.2017.07.007.

Rhee, Inkyu et al. 2015. "Compressive Strength Sensitivity of Cement Mortar Using Rice Husk-Derived Graphene with a High Specific Surface Area." *Construction and Building Materials*

96: 189–97. http://dx.doi.org/10.1016/j.conbuildmat.2015.08.016.

Safian, Muhammad Taqi uddeen, Khalid Umar, and Mohamad Nasir Mohamad Ibrahim. 2021. "Synthesis and Scalability of Graphene and Its Derivatives: A Journey towards Sustainable and Commercial Material." *Journal of Cleaner Production* 318(August): 128603. https://doi.org/10.1016/j.jclepro.2021.128603.

Saha, Jhantu Kumar, and Animesh Dutta. 2021. Waste and Biomass Valorization *A Review of Graphene: Material Synthesis from Biomass Sources*. Springer Netherlands. https://doi.org/10.1007/s12649-021-01577-w.

Sekhon, Satpal Singh, Prabhsharan Kaur, and Jin Soo Park. 2021. "From Coconut Shell Biomass to Oxygen Reduction Reaction Catalyst: Tuning Porosity and Nitrogen Doping." *Renewable and Sustainable Energy Reviews* 147(May): 111173. https://doi.org/10.1016/j.rser.2021.111173.

Stojanovska, Elena et al. 2019. "Developing and Characterization of Lignin-Based Fibrous Nanocarbon Electrodes for Energy Storage Devices." *Composites Part B: Engineering* 158: 239–48. https://doi.org/10.1016/j.compositesb.2018.09.072.

Sujiono, E. H. et al. 2020. "Graphene Oxide Based Coconut Shell Waste: Synthesis by Modified Hummers Method and Characterization." *Heliyon* 6(8): e04568. https://doi.org/10.1016/j.heliyon.2020.e04568.

Wang, Min, Sung Kyu Jang, Young Jae Song, and Sungjoo Lee. 2015. "CVD Growth of Graphene under Exfoliated Hexagonal Boron Nitride for Vertical Hybrid Structures." *Materials Research Bulletin* 61: 226–30. http://dx.doi.org/10.1016/j.materresbull.2014.10.033.

Whitener, Keith E., and Paul E. Sheehan. 2014. "Graphene Synthesis." *Diamond and Related Materials* 46: 25–34. http://dx.doi.org/10.1016/j.diamond.2014.04.006.

Xue, Beichen et al. 2021. "Sustainable and Recyclable Synthesis of Porous Carbon Sheets from Rice Husks for Energy Storage: A Strategy of Comprehensive Utilization." *Industrial Crops and Products* 170(May): 113724. https://doi.org/10.1016/j.indcrop.2021.113724.

Yang, Kunbin et al. 2010. "Preparation of High Surface Area Activated Carbon from Coconut Shells Using Microwave Heating." *Bioresource Technology* 101(15): 6163–69. http://dx.doi.org/10.1016/j.biortech.2010.03.001.

Zhu, Linfeng et al. 2017. "Black Liquor-Derived Porous Carbons from Rice Straw for High-

Performance Supercapacitors." *Chemical Engineering Journal* 316: 770–77. http://dx.doi.org/10.1016/j.cej.2017.02.034.