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Review

The Importance of Sustainable Biomass Sources in the Development of Porous Carbonaceous Materials-Synthesis and Energy Applications: A Review

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Abstract: In this review, a variety of planning methods for porous organic materials using different types of biomasses are compiled, and their functions are discussed. Improved pore architectures and variable surfaces were created in porous carbons manufactured from biomass. It is effective and sustainable to use biomass waste, which mostly consists of cellulose, hemicellulose, and lignin. They assemble microtextured structures around one another in multi-channel configurations. The possibility of incorporating porous carbon compounds derived from biomass is being explored due to their distinct surface and structure. These "old type" carbons, which are produced through direct pyrolysis or physical or chemical activation, represent the instantaneous usage of biomass. There has been a lot of research on the chemical activation of biomass to create extremely effective activated porous carbons for gas collection. They consist of a variety of small patterns, pore dispersions, and conductive spines and have adaptive physicochemical properties that permit their application as dynamic stage networks or electroactive materials. The structure of carbon-based materials obtained from biomass has the potential to improve electrochemical energy storage. Energy storage resources are required more frequently every day. Energy storage is essential to meet the energy demands resulting from the interruption of energy sources due to several circumstances. There are many uses for carbon materials, including the storage of energy, the filtration of water and air, and the storage of gases like carbon dioxide (CO_2), nitrogen (N_2), methane (CH_4), and hydrogen (H_2). In this study, the advantages of cellulose-based systems as well as the latest developments and methods for creating high-capacity electronics are highlighted.

***Keywords*:** Biomass, Porous carbon materials, Biochars, Sustainable energy storage, Power storage

1. Introduction

Global population growth is surpassing technical development, which leads to a significant rise in energy consumption. The use of renewable energy sources is now more important than ever due to the growth in energy consumption and the unsustainable nature of non-renewable energy sources. The main quality of sustainable resources is that they continue to have the same shape and give off an identical quantity of energy after usage. Eco-friendly energy has made it possible for economic systems to be truly sustainable, to look for new resources, and to develop a cost-effective method of supplying energy. In a broad sense, biomass, one of the most environmentally acceptable power sources, refers to all materials derived from living organisms, and it also has the highest potential for use. Biomass is widely acknowledged as a valuable renewable energy source due to its widespread availability, versatility, capacity to regulate environmental conditions, and the exciting possibility of exploring its structure. The production of energy and carbon compounds via thermochemical biomass conversion processes has been the subject of numerous studies, in particular. Numerous substances are used as energy storage substances, including zeolite, pumice, ceramic, activated carbon (AC), carbon-based substances, etc. Carbon-

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based materials are preferred because of their lightness, abundance, ease of processing, cheapness, high conductivity, high surface area, non-toxicity, wide operating temperature range, and high stability.

Micropores with a pore size width of less than 0.7 nm belong to the category of ultrafine micropores, according to the IUPAC classification and earlier studies [1,2]. Biomass can be used to create ultra-microporous compounds, which are carbon materials of various sizes, shapes, and chemical natures. The biggest issue with ultra-microporous materials made from biofuels and biomass is the shrinkage of planting areas for crops used to make biofuels on agricultural lands, which harms food crops and leads to higher costs. For this reason, the use of biomass waste in the production of ultra-microporous materials from biomass has come to the fore. Carbon materials have many important applications, such as energy storage, the removal of pollutants, gas storage, carbon fuel cells, and catalysts [3,4]. Biomass-derived porous carbon is among the materials investigated for gas separation due to its advanced pore structures, tunable surface chemistry, low cost, and excellent separation performance [5]. However, the pore size distributions are still very difficult to control. The wide size distribution of pores causes low selectivity in the gas mixture [6]. For these reasons, ultra-microporous structures prepared from biomass are needed. These highly controlled carbon materials can significantly improve their gas separation performance [7].

Biochar (BC) is a more specific term for the substance obtained by the temperature-trade/pyrolysis of natural materials, usually at low temperatures (700 °C) and with a constrained amount of oxygen [8]. Several different types of biomasses, such as agricultural waste, ranger service waste, and sewage sludge, can be used to produce BC. Due to the large number of micropores formed during the pyrolysis reaction, it can also have a large surface area. Utilizing BC, which has incredibly variable pore size and shape, might significantly alter its suitability depending on the conditions of formation. The specific features of the natural component utilized for producing BC have a significant impact on its porosity, which varies.

The present article evaluates recent research on the manufacture of carbonaceous materials from biomass for the development of a low-carbon, eco-friendly system that safeguards the environment, offers a dependable worldwide power source, increases productivity, and lowers energy consumption. Biomass has a significant potential to contribute to energy and ecological goals, but it must be produced in environmentally, socially, and economically sustainable ways. The advantages in terms of the environment, society, and finances can be influenced by a variety of factors, and there are several options for using biomass as energy. It has been analyzed how biomass sources, which can be a key determinant of the generation of carbon products using biomass, work.

1.1. Sources of Biowaste

The origin and nature of the raw materials play a decisive role at the beginning of the most economically important BC production parameters. Production techniques can be applied depending on the raw material. Some of these can be counted as agro-forest residues, algal biomass, and industrial biomass residues (Figure 1). Algae biomass refers to the creatures that live in streams together with the sea and lake and are seen as a green cover with their wide variety. The use of algae, a third-generation biofuel, as a substitute for fossil fuels is a solution that has been adopted globally [9]. Since algae use CO_2 as a carbon source, they reduce CO_2 emissions. With the production of biofuel, which is a renewable energy source, the related environmental impacts are minimized. On the other hand, it is advantageous to use it as a source of biowaste, as it grows on lands that are not suitable for agriculture. Algal biomass has certain advantages over field-grown biomass as a raw material for BC production. It has a short harvest cycle and does not need a large land area for cultivation. However, the type of algal biomass used must also be considered when producing BC-based materials, as its chemical composition is species-dependent. Industrial biomass residues are wastes that are rich in carbon content in many industrial sectors. These include tea waste, corn cobs, olive seeds, fruit waste, fish waste, wood-based industries producing sawdust, paper industry, etc. Industries that produce residues such as these high value-added materials, obtained from carbon-rich industrial residues, are highly preferred because they can be produced in large quantities.

The sources of biochar are sewage sludge, animal waste (slaughter waste, animal fat), feces, bones, etc. Other biomass sources, such as lignocellulose, may also be used as a framework for it. However, in this study, only plant-based biowastes will be mentioned. BC from biomass is typically 20–40% of dry lignocellulosic biomass. The forestry, food, and agricultural sectors which are the main suppliers of raw materials produce the majority of the biowaste [10]. The most typical biowastes are sawdust, pulp, a pressed cake from the beverage sector, rice residue, and crop wastes. Hernandez-Mena et al. [11] used bamboo as a source of biomass to produce biochar. The new BC obtained by them has high porosity, with sizes ranging from micropores to macropores (10–200 μm).

Figure 1. Sample images of biowastes.

1.2. Effects of Feedstock Material

BC obtained from biomass is a carbon-rich material. Biochars are obtained by carbonizing the organic structure of biomass at high temperatures in an oxygen-free environment (Figure 2). As a result of this thermochemical pyrolysis, while the volatile components in the structure are removed, the organic components become carbonized, and renewable carbon with a high carbon content (75–85%) is obtained [12].

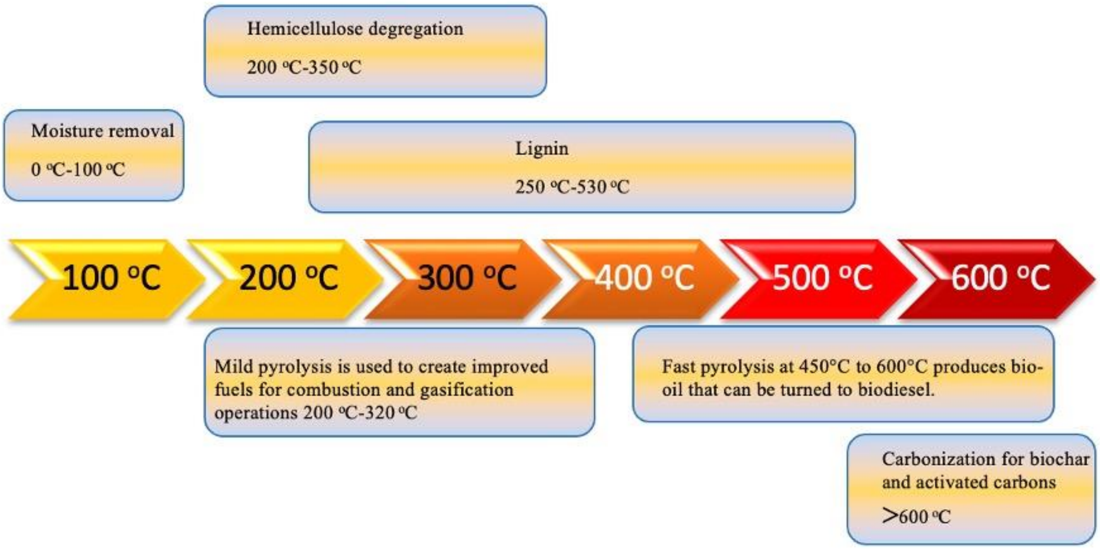

Figure 2. Cellulosic biomass with a thermal degradation spectrum.

The main reason for such high stability is the constitution of nanostructured materials [13,14]. The substantially larger ratio of potent aromatic structures is one of the chemical characteristics that distinguishes BC from other organic materials [15]. The intense aromatic nature of biochar has different forms (amorphous C-predominant at low pyrolysis temperatures, turbostratic C, and graphite C-formed at high temperatures). The properties of biochar are strongly influenced by operating conditions such as the temperature of the production process, heating rate, holding times, raw material particle size, and feedstock. Zhao et al., [16] showed that both raw material properties and production conditions affect biochar properties.

Bamboo vascular groups produce large holes that are essential for improving soil quality because they may operate as a home for symbiotic bacteria, and these pores could also function as release paths for the pyrolytic vapors produced in the process. It has been shown that the surface and porosity of biochar change as the pyrolysis temperature increases during the production process [17]. For this variation, one could suggest that it is the result of the growth of voids and the decomposition of organic matter in the structure [18]. During pyrolysis, functional groups containing large amounts of oxygen in cellulose and hemicellulose are eliminated as H_2O, CO_2, and CO, and micropores are formed. Meanwhile, lignin contains aromatic units in its structure that produce chemically inert, non-porous carbon materials. Along with the destruction of the structure's aliphatic alkyl and ester molecules, the aromatic lignin core may also be subjected to higher pyrolysis temperatures and rapid heating rates, increasing the surface area.

The abundant hydroxyl groups in cellulose and hemicellulose are easily dissociated due to their higher activity when compared to the stable aromatic compounds in lignin [19]. Many hydroxyl groups in both cellulose and hemicellulose structures degrade more rapidly due to their increased activity compared to the fixed compounds in lignin. Hemicelluloses have a straight chain backbone, are highly branched, have a low degree of polymerization (100–200) compared to cellulose, and tend to degrade completely at high temperatures (~ 900 ºC) [19]. Dehydration, condensation, and degradation are processes that occur in hydroxyl-containing cellulose and hemicellulose, resulting in abundant micropores when $KHCO_3$ is added during the pyrolysis process [19]. These hydroxyl groups in the different cellulose or hemicellulose units bind to each other and undergo dehydration and condensation, which creates a three-dimensional structure. The three-dimensional structure is produced by the hydroxyls of various cellulosic or hemicellulose units linking with one another, going through dehydration, and then condensation. In contrast, the aromatic rings in lignin lead to the formation of a robust structure that leads to non-porous carbonaceous materials under direct pyrolysis treatment. Another reason can be said to be that by increasing the temperature, the substances that block the pores are removed or thermally broken, thus increasing the surface area accessible from the outside [20]. Scientists have produced biochar through the pyrolysis of a variety of waste products, including sawdust, coffee grounds, sugarcane pulp, and walnut wood. They have tested it in various fields for waste recycling and have determined that it is an effective technique.

Igalavithana et al. [21] investigated global environmental problems, such as the environmental threats posed by the disposal of unsustainable food waste. BC was produced from mixtures of wood waste and food waste prepared in different proportions. They determined that the specific surface area of the biochar they synthesized decreased with an increase in food waste in the raw material mixture. The largest surface area (294.7 m^2/g) was reached when the wood waste ratio was highest in the mixture [22]. Another reason was thought to be that the high ash content in food waste clogs the pores, causing a decrease in the surface area. In another study, Igalavithana et al. [21], a mixture of pinecones and plant wastes was converted into biochar. In their study on the importance of the raw material for the produced biochar, they found the specific surface areas to be 1.16 m^2/g, for the BC produced from plant waste, 192.97 m^2/g for the BC produced from a pinecone, and 50.26 m^2/g for the BC produced from the mixture.

Zhao et al. [23] reported that the properties of BC obtained from apple tree branches at different pyrolysis temperatures (300, 400, 500, and 600 °C) changed. It was determined that the fixed carbon (C), and inorganic mineral content in the BC structure increased with increasing temperature, while the yield, volatile substance content, cation exchange capacity, and O/C and H/C ratios decreased. Brunauer-Emmett-Teller (BET) micropores have a larger surface area and volume at high temperatures due to increased surface area and micropore volume. This increase in pore volume and surface area may be due to the gradual degradation of organic materials (hemicelluloses, cellulose, and lignin) contained in the biowaste used as raw materials and the formation of vascular bundles. Another possibility is that the formation of the channel structure during the pyrolysis of these organic structures may result from the formation of intercellular spaces or the development of intercellular spaces [24]. The presence of vascular bundles supports the formation and release of volatile compounds. Hemicellulose in the structure has high reactivity during the formation of channel structures in the pyrolysis process [24,25]. During pyrolysis, the decomposition of hemicellulose together with organic components in the structure increases the formation of the micropore structure. On the other hand, some amorphous carbon structures are formed because of the deterioration of the cellulose structure [23]. These amorphous carbon structures can be used to create micropores [26]. Thus, there will be an increase in surface area and pore volume. The effect of lignin in the structure on pore formation is thought to cause more pore formation due to the deterioration of the lignin structure during pyrolysis and the increase in the release of volatile matter.

1.3. Use of Biowaste in Energy Sources

Energy resources are rapidly decreasing day by day. On the other hand, energy storage is important to meet the energy needs arising from the interruption of energy sources. The thermochemical conversion of biomass provides an option to produce liquid fuel, syngas, and porous carbon [4] (Figures 3, 4). From an economic and environmental perspective, porous carbon compounds should be synthesized using risk-free scientific methods and from inexpensive, sustainable sources. Because of their extensive use in critical application areas such as CO_2 capture, fuel cells, energy storage, gas storage, and catalytic supports, porous carbons have attracted the most attention among these high-value items. The porous carbons have exceptional chemical and physical characteristics, have a large BET surface area, may vary the arrangement of pore sizes, and exhibit excellent electrochemical performance. For these reasons, the tendency to seek new alternative and clean energy sources and storage has increased. With advances in technology, efficient storage of clean energy is becoming more and more important. However, when it comes to the synthesis and production of porous carbon materials for use in carbon electrodes in energy applications, biobased resources provide considerable economic advantages. This is so because many of biomass resources are leftovers from agriculture or industry. Additionally, the majority of biowaste from food and plants is almost free.

When investigating sustainable and more economically viable methods for the synthesis of porous materials from biowaste, it is preferable to eliminate the need for carbonization and simplify the synthesis process, especially before activation. Durán-Jiménez et al. achieved high efficiency of CO_2 capture (5.3 mmol/g) with AC prepared by a microwave pyrolysis-activation process in one stage using biomass as a raw material (low KOH and K_2CO_3 impregnation ratio) [27]. It was concluded that the pyrolysis activation also increased the formation of ultra-micropores, leading to high CO_2 uptake. In this study, the pre-carbonization step eliminated the use of high amounts of activator and provided a significant reduction in processing time compared to the long time required in conventional processes, such as 4–6 hours. For carbon samples prepared using KOH and K_2CO_3 as agents, surface areas are 608–1000 m^2/g, and 842–974 m^2/g and pore volumes are 0.25 to 0.39 cm^3/g and 0.31 to 0.40 cm^3/g, respectively. Singh et al. [28] synthesized highly efficient porous biocarbon with high ultra-microporosity by combining a readily available renewable biomass, lotus seeds, for both pre- and post-combustion CO_2 trapping. The materials created are ultra-microporous and have bimodal porosity that may be controlled simply by changing the experimental conditions. The surface area can be changed from 1079 m^2/g to 2230 m^2/g by adjusting the activator concentration and carbonization temperature. The material that was designed to have the largest surface area and pore volume showed great potential for both low-pressure (6.8 mmol/g at 1 bar/0 °C) and high-pressure applications (26.4 mmol/g at 30 bar/0 °C) CO_2 capture. The ultra-microporosity, a significant surface area, and surface-oxygenated functional groups provide the best performance. Tar evacuation is one of the biggest challenges in the biomass gasification process for eco-friendly power. Many scientists define tar as a condensable hydrocarbon complex consisting of complicated polycyclic aromatic hydrocarbons, various hydrocarbons containing oxygen, and polycyclic sweet-smelling molecules [29] due to the extraordinarily high carbon and N_2 percentages in the composition of biomass tar. Using a straightforward activation technique, Li et al. [30] was able to produce nitrogen-doped high ultra-microporous carbon because biomass tar has a very high N_2 and carbon percentage in its structure. Additionally, at 273 and 298 K, respectively, the N_2-doped ultra-microporous with equally distributed active sites had outstanding CO_2 absorption capacities of 6.02 and 4.11 mmol/g (1 bar).

Pine pellets from a carpentry factory were used by Zhang and colleagues [31] to create a porous carbon material, and they investigate the usage of this new carbon material for H_2 storage. They looked at how the framework of porous carbon was affected by variables including pyrolysis temperature and heating rate. The porous carbon material with the highest surface area (1703 m^2/g) was found to have been produced under the parameters of pyrolysis temperature (823 K), heating rate (10 K/min), and carbon-containing pretreatment temperature (473 K). They discovered that at atmospheric pressure and 77 K, the H_2 adsorption capacity of this freshly created porous carbon substance was 170.12 cm^3/g (1.53% by weight). An innovative, sustainable preparation approach was provided in the present investigation.

At this point, cleaner renewable fuels such as natural gas (CH_4) and hydrogen gas (H_2) must quickly replace fossil fuels as the main source of energy for mobility in the global economy. Selecting an appropriate adsorbent that can store the gas and meet the necessary available energy capacity is a significant difficulty in natural gas adsorption. The qualities of the sorbent must be considered before selecting one. Adsorption onto porous materials requires distinctive adsorbent properties: pore volume, surface area, and pore size. According to this research, AC may adsorb CH_4 up to 300 v/v [32].

Numerous studies have shown that high surface area (>1000 m^2/g), high pore volume, and an average pore diameter in the range of 8–15 are favorable for CH_4 adsorption [33]. To find the AC pore size that offers the best

CH_4 adsorption in terms of gas retention and kinetics, numerous investigations have been conducted [7,32–34]. It is well known that CH_4 gets adsorbed into the AC structure's pores and that, depending on the pressure exerted, the pores fill with CH_4. For instance, Mosher et al. found that AC with plenty of 1.2 nm micropores was the best gas adsorbent for CH_4 [34]. They discovered that this typical pore size allows for ideal gas confinement.

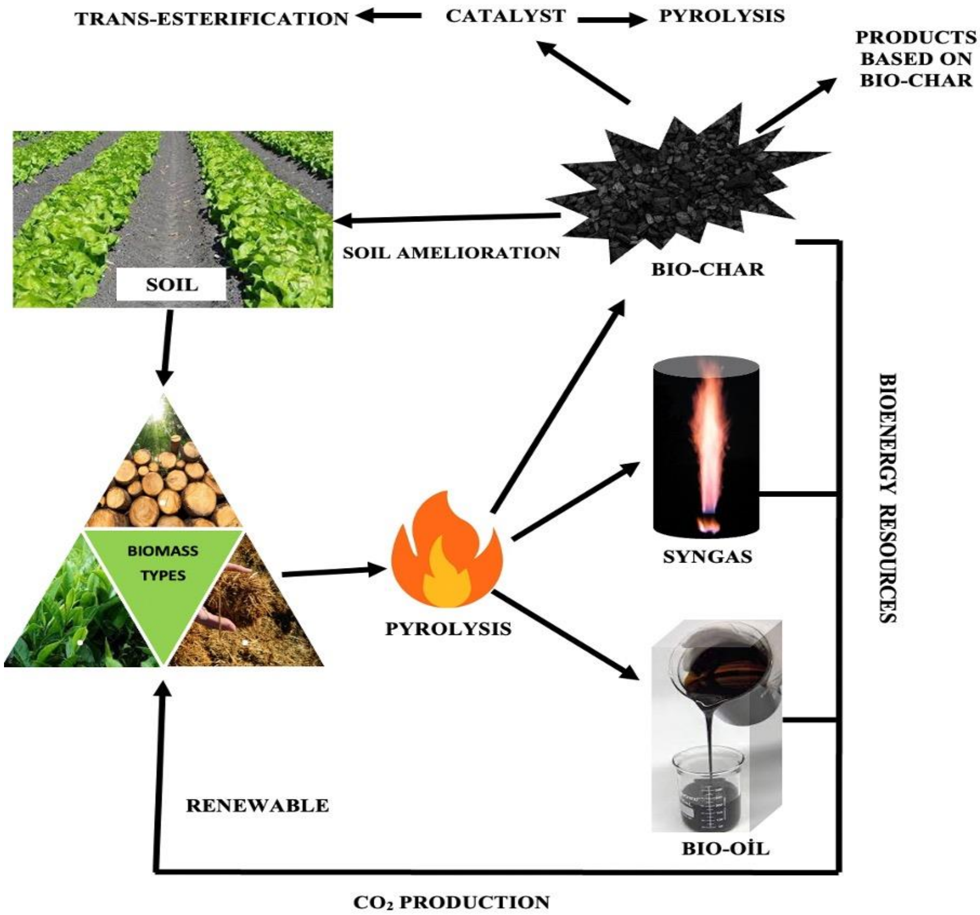

Figure 3. Energy generation using processed biomass.

1.4. The Natural Materials for Sustainable Energy Storage

The most effective power storage and conversion tools to fulfil energy requirements are electrochemical energy systems like batteries, supercapacitors, and fuel cells. The electrodes are the most important part that affects the performance of these devices. Electrochemical properties of the electrode, pore shape and size, pore size distribution, high thermal and chemical stability, specific surface area, and surface functional groups are directly related [35]. Carbon materials, conductive polymers, and metal oxides are widely used as electrode materials. Carbon materials are highly preferred due to their superior properties, such as high pore structure, stability, and adjustable pore size distribution, as well as their low cost. Based on this, biomass is the ideal option for producing a new era of inexpensive, abundant, and ecologically beneficial polymer electrodes. Research on the development of energy storage materials in which biomass is used as a sustainable, renewable, environmentally friendly, alternative, and clean carbon source (Figure 4) in electrode construction has recently become one of the most popular research topics.

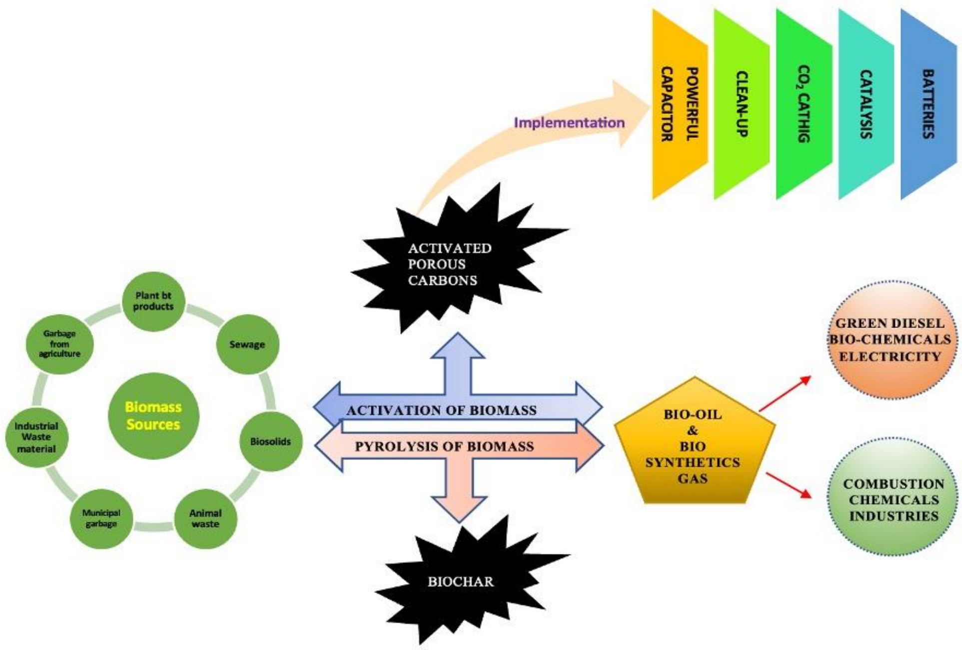

Figure 4. A flowchart that shows how BC and AC carbon are produced from carbon sources and their respective uses.

The use of biomass in the synthesis of chemical compounds and renewable energy sources is very interesting. To produce heat, electricity, H_2, value-added chemicals, and fuel, biomass reserves must be plentiful, renewable, and minimal in N_2 and sulfur (S). Because biomass is renewable and sustainable, it has attracted a lot of interest from many sources. The selected biomass precursor must have a high carbon content to generate large yields during pre-carbonization and active processing. The use of these sustainable chemical and fuel sources will be critical when researching innovative, low-cost biomass. Biomass, a significant worldwide energy source, may be able to responsibly meet energy requirements. If the appropriate conversion techniques are applied, all these renewable sources can eventually play a substantial role in the energy generation process.

The use of biomass as an energy storage material obtained by various methods attracts attention today. Due to their high-power density, long cycle time, and quick charging and discharging capabilities, supercapacitors have received more attention in recent years in research on this topic (Figure 5). An electrode material should have a high surface area and a highly porous structure to offer an adequate active site for electrochemical oxidation. These applications allow the use of common carbon materials such as carbon nanotubes, graphite granules, graphene, and granular AC [36]. However, the high cost of carbon materials often restricts their use. Compared with BC, such carbon materials have comparable surface areas and porous structures. The cost of using BC as an electrode material is far lower, though. Therefore, BC, a porous material, can be an alternative to electrode materials.

By using a quick and low-cost one-step KOH activation, Chen et al. [37] created N_2-self-doped three-dimensional (3D) honeycomb porous carbon from cottonseed waste husks. The carbon material showed abundant N self-doping, a high specific surface area of 1694.1 m^2/g, and hierarchical micro, meso, and macropore structures. At current densities of 0.5 A/g and 20 A/g, respectively, they discovered that employing these synthetic carbon materials as electrodes produced high specific capacitances of 238 F/g and 200 F/g and an excellent yield of 84%. The capacity retention rate was discovered to be high. Aside from having a high specific capacitance value of 52 F/g at 0.5 A/g and an energy density of 10.4 Wh/kg at 300 W/kg, the synthesized carbon material-based symmetric supercapacitor also has a capacitance retention of 91% after 5000 cycles. From this study, they concluded that the technology to fabricate porous 3D honeycomb carbon composites from cottonseed husks is simple, affordable, and suitable for industrial manufacturing.

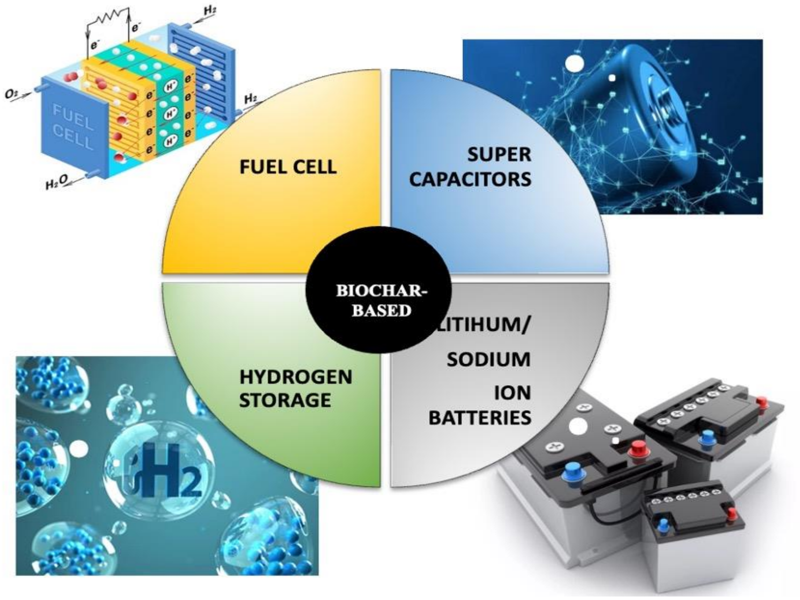

Figure 5. Application of BC-based natural polymer materials for storing and converting energy.

Table 1. Comparison of specific capacitance of the biomass-derived porous carbon materials.

Biomass	S_{BET} (m^2/g)	S_{mic} (m^2/g)	V_{mic} (m^3/g)	V_{Total} (m^3/g)	Capacitance (F/g)	Current density (A/g)	Ref.
Sunflower seed	1162	1096	0.560	0.620	244	10	[36]
Peanut shells	1428	1068	0.416	0.550	248	1	[38]
Cassava peel	1186	772	0.312	0.501	264	-	[39]
Pine tree residues	3014	-	-	-	200.6	-	[40]
Sugar cane	2090	1800	0.281	-	103	-	[41]
Butnea monsperma flower pollens	1422	633	0.327	0.767	130	-	[42]
Grain waste	2959	-	0.830	1.650	260	0.6	[43]
Pine cone	2007	1853	0.800	-	87.1	-	[44]
Cassava peel	634	595	-	0.342	257	1	[45]
Chestnut shell-derived N/S-doped porous carbons	1353	-	-	0.560	318	0.5	[4]
Leaves (Fallen)	1078	636	0.274	0.939	242	0.3	[46]
Corncob residue	1210	900	0.416	0.671	314	1	[47]
Sugar cane bagasse	1452	-	0.480	1.740	300	50	[48]
Waste tea leaves	2841	-	-	1.366	330	1	[49]
Waste tire	563	-	0.167	0.201	106	1	[50]
Bagasse	1892	-	0.580	0.860	142	0.5	[51]
Prawn shells	1606	1554	-	0.650	357	0.05	[52]

There are differences in BC production due to the differences in the chemical composition of biomass, which consists of organic molecules (cellulose, hemicellulose, lignin) and inorganic elements (sodium, iron, potassium, etc.). It is important for ion mobility due to its high carbon content, superior pore structure, and surface properties. BC 's amorphous structure contributes to the improvement of its electrical properties. BC is generally rich in surface functional groups (-COOH, -OH, -C, -O), allowing the capacitance values to be improved and the addition of other atoms to the structure [15, 25, 40, 53]. By enhancing BC's pore structure, electrical, and surface properties, the capacitance value can be raised. For example, the amorphous carbon material of BC has recently started to attract attention in lithium-ion battery applications. The biomass type can be diversified with parameters such as applied pyrolysis temperature and pyrolysis time. The term "BC carbon" refers to carbon that still exists in the structure but lacks a regular crystal structure. This H_2 content is effective in generating high lithium capacity in lithium-ion batteries. On the other hand, the surface functional groups of BC, especially the oxygen-containing acidic carboxyl and phenol groups, increase the specific capacitance through the formation of reversible redox reactions. The carbon material also provides high ion capacity. In addition, activation with chemicals such as H3PO4, $ZnCl_2$, and KOH increases the capacity performance of the carbon material.

Understanding the chemical activation mechanism during biomass pyrolysis is essential for making better use of the generated BC. One study [54], for instance, examined the role of KOH activation in biomass rich in oxygen groups. They preferred bamboo waste as biomass. The results showed that KOH may effectively react with active O-containing species in biomass in the primary reaction, which occurs at lower ratios (1:8–1:2) and lower temperatures (400–600 °C). On the other hand, it has been proposed that at low temperatures, KOH reacts with the biomass and completely changes into K_2CO_3, producing large amounts of gaseous products and byproducts such as phenols. It was found that as the temperature increased, phenol release decreased, and K_2CO_3 changed into K_2O. Numerous holes were produced during the BC-making process because of interactions between KOH, O-containing functional groups, and ambient carbon fragments. It was discovered that the interactions between KOH and biomass led to a significant increase in a specific surface area with higher temperatures. As seen in Table 1, it is seen that energy storage materials have been developed by using different activations and electrolytes from different types of biomasses.

The creation of sustainable energy storage devices is considerably aided by the porous and naturally AC that may be obtained from biomass [55]. The 3D cross-linked network structure of the synthesized AC consists of aromatic units and hydroaromatic groups found in the structure of plants [56]. The most important element of the electrochemical performance of carbon electrodes made from biomass in energy storage applications is the raw material. The porosity, pore size, and specific surface area of a carbon-based electrode all affect how well it performs electrochemically. Biomass-based carbon electrodes exhibit distinctive nanostructures, a large amount of heteroatom structure, and a high specific surface area [57]. Although it varies from source to source, in general, a large part of the biomass structure (85–90%) consists of cellulose, hemicellulose, lignin triple system, and extractable substances, and the remaining part consists of organic (protein, oil, etc.) and inorganic (ash) substances. The ratios of cellulose, hemicellulose, and lignin in the structure of lignocellulosic biomass vary from biomass to biomass (Table 2).

Table 2. Composition of different lignocellulosic substrates; cellulose, hemicellulose, and lignin content [58–60].

Lignocellulosic Biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Bamboo stem	43.04	22.13	27.14
Barley straw	44	27	7
Cane bagasse	36	28	20
Cane straw	36	21	16
Card board	47	25	12
Coastal Bermuda Grass	25	35.7	6.4
Corn cob	42.0	45.9	2.8
Corn stalk	36.4	30.3	6.9
Corn stover	42.21	22.28	19.54
Corn straw	49.3	28.8	7.5
Cotton seed hairs	80–95	5–20	0
Cotton stalk	41.6	23.6	23.3
Cotton straw	42	12	15
Empty fruit bunch	34.9	26.64	31.1
Grass	47.12	36.01	11.55
Oat straw	35.0	28.2	4.1
Oil palm empty fruit bunch	38.5	26.1	11.6
Poplar	46.0	16.7	26.6
Rice hulls	36.0	12.0	26.0
Rice straw	37.8	29.6	14.8
Spruce	24.7	10.2	35.0
Sawdust waste	31.5	26.1	24.9
Sweet sorghum	45	27	21
Switchgrass	45	31.4	12
Sugarcane bagasse	46.1	20.1	20.3
Sunflower stalk	34	20.8	29.7
Wheat straw	43.4	26.9	22.2
leaves	15–20	80-85	0
Maize straw	36	28	29
Nut shells	25-30	25-30	30-40
Pine tree	44	26	29

Cellulose is a complex carbohydrate that can be used to create supercapacitors and cells because of its special shape, vast availability, attraction, biocompatibility, flexibility, and mechanical qualities [61]. Cellulose holds great promise because of the ease with which electrodes can adapt their structural and mechanical properties, especially for the design of energy storage devices to meet our growing demand for energy and sustainability. Materials made from cellulose have a large active surface area because the amount of cellulose in the material has a big impact on how porous the BC becomes. For this reason, it is reported that higher cellulose content is beneficial for improving the catalytic activity of BC [19]. The adaptability of cellulose as an electrode material for batteries and supercapacitors was highlighted by Wang et al. in 2017 [61]. The authors' work emphasizes cellulose characteristics such as pores, pore dispersion, pore size distribution, and crystalline nature that are linked to high efficiency. It is asserted that BC with increased cellulose content has better catalytic activity [19]. Hemicellulose is another important polysaccharide that binds cellulose and lignin by hydrogen and covalent bonds. Hemicellulose is a branched heteropolysaccharide formed by combining different sugar units such as pentose sugars (arabinose, xylose, etc.), hexose sugars (glucose, mannose, etc.) and sugar acids in different ways. It should be noted that lignin is a biopolymer consisting of phenolic groups that can be changed to produce quinone groups, which can release electrons through redox reactions [62]. The unique structure and composition of lignin can be effectively used for the synthesis of functional materials [63].

Ma et al. [64] developed a new method for in-situ production of activated porous carbons using zinc complexes from tobacco stems. Through hydrothermal treatment, the C-OOH and C-OH groups in the tobacco stem coordinated to form zinc (Zn) ions, and the presence of the novel Zn provided an additional 144% ultra-micropore volume. These newly synthesized Zn-hydrochars were then used as a template to create a microporous structure. Under 1 bar, a higher capacity to adsorb CO_2 of 209 and 146 mg/g was achieved at 0 °C and 25 °C, respectively. They developed microporous graphite carbon with connected ultra-micropores by simultaneously activating and shaping peanut shell charcoal, which they used as an efficient site for tiny sulfur molecules in Li-S batteries. The cell still produces substantial capacity, 570 mAh/g at 4 °C and 1146 mAh/g at 0.1 °C. Capacities of 826 and 571 mAh/g remain after 1000 cycles at 1 °C and 2 °C. The advantages of ultra-microporous BC allowed the composite to perform extremely well electrochemical performance. It has been reported that this composite prepared from peanut shells has ultra-micropores with very small (<0.4 nm) pore widths. This study shows that the ultra-micropore size in the resulting composite structure is essentially the smallest among the several porous carbons produced for sulfur loading.

Large-scale, low-cost, and eco-friendly manufacture of sulfur/carbon composite materials is expected to provide significant advantages for Li-S battery applications. Zhang et al. [7] organized tea bark porous carbons with negligible nitrogen content and narrow pore sizes (pore width 1 nm). It is possible to cook the tea bark with tea oil. 60% of organic tea oil products consist of strips and have no oil. As a result, a lot of oil-tea bark is dumped regionally or just reproduced, seriously polluting the environment. These new ultra-microporous carbons were used as potential adsorbent materials to separate the CO_2/N_2, CO_2/CH_4, and CH_4/N_2 and CO_2 catch gas blend matches. The relationship between the ultra-micropore size and CO_2 was about the adsorption limit. The BET surface region of the carbonaceous was completely settled as 2676 ±107 m^2/g. This demonstrated that the CO_2 adsorption limit at 1 bar was supplied by ultra-micropores (1 nm).

2. Conclusions

The most recent developments in carbons made from biomass are examined in this paper, along with how the preparation and feedstock of carbonaceous material affect the porous structure. The need for energy is growing steadily because of global population growth and technological advancement, and lignocellulosic biomass provides the most abundant and eco-friendly form of energy on earth. Structures with a wide pore size distribution from micropores to macropores, are typically obtained by using a synthetic implementation method when designing biomass-inferred porous carbons. Carbon-based materials with highly defined pores are challenging to prepare. Cellulose, the most common organic biomaterial, is a unique, environmentally friendly, and useful material with interesting features. High gas retention was achieved due to the increased development of ultra-micropore during pyrolysis activation. It is ideal for use in adaptable, self-sustaining energy storage systems because it possesses a variety of levelled fiber forms, a wide surface area, heat resistance, water solubility, bioactivity, and mechanical stability. The study of ligno-based energy storage devices is currently through some significant improvements as novel hybrid composites, inventive structures, and biomass-based devices are being constructed with larger surface mass loadings and excellent overall capacities. High-efficiency biomass utilization is a fascinating new area in technology and science as energy and environmental concerns gain greater visibility. The physicochemical characteristics, flexibility in structure, and renewability of biomass-based carbon materials have demonstrated significant and promising futures in the fields of energy storage and conversion. The disciplines of energy conversion and storage have advanced significantly, and the production and usage of carbon compounds based on biomass are rapidly expanding. However, there are still some problems which will need to be addressed and fixed in the future.

Conflict of interest

There is no conflict of interest for this study.

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