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# Recent advancements in synthesis and applications of biochar derived from lignocellulosic biomass

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***Abstract*** - Biomass accumulation poses a serious problem with rapidly growing global population and fast urbanization. Development of strategies for utilizing biomass is significant as it can be used as a source of renewable energy, in mitigating climate change, waste management, sustainable agriculture etc. Lignocellulosic biomass can be converted into Biochar in context to the environment. Efficiency of Biochar depends on several factors like type of feedstock, reaction environment, pyrolysis temperature, operating conditions etc. during process of pyrolysis. Along with sources of feedstock, method of carbonization and activation methods review also deals with applications of biomass in area of adsorption, catalysis, energy storage for environment friendly alternative and to provide practical solution with respect to environment and energy demands. This paper offers a comparison of several LBC preparation techniques and in-depth knowledge of the advantages and limitations to develop it for long term use.

Keywords: Biomass, Lignocellulose, Bio char, Feedstock, pyrolysis

## I. INTRODUCTION

The rapid urbanization and population growth have resulted in a surge in energy needs that is placing significant strain on the availability of conventional energy sources [1] . Renewable sources of energy and sustainable technologies prove to be a better substitute for reducing reliance on fossil fuels while mitigating environmental effects. Bio lignocellulosic biomass is the type of biomass characterised by presence of lignocellulosic fibre [2]which can be sourced from materials like municipal [3], forest and agro waste [4] , forest and agricultural residue [5] etc. Bio lignocellulosic biomass is rich in lignin and has a high carbon content and is an ideal precursor for lignocellulosic biomass-derived biochar,or LBC [6]. LBC due to its extended surface, special porous structure, and significant energy content find wide applications in the field of agriculture, environment, industries, energy production etc. The conversion technologies are outlined in this review with respect to LBC's and focuses on methods of carbonization, activation and applications of LBC's in various fields.

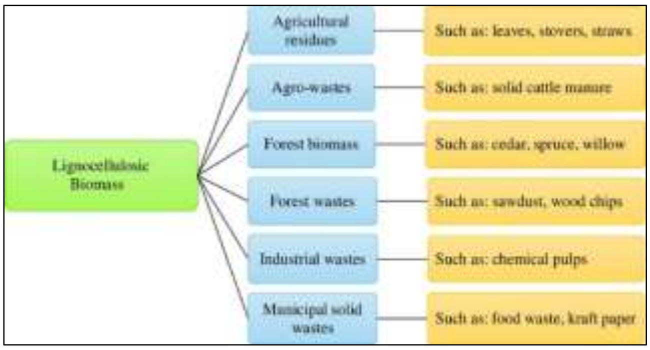


Fig. 1: Different sources of Lignocellulosic biomass

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## II. PREPARATION METHODS FOR LBC'S

**2.1 Carbonization Methods**- This process involves induction of pyrolysis of the precursor in an inert atmosphere to produce charc oal. With physicochemical and structural rearrangements via heating, which increases the carbon content of the organic matter. The pores formed during carbonization are usually narrow and sometimes clogged with tarry materials. The release of tar material occurs when dissolved particles in the carbon matrix diffuse into the gas through the pore structure. Some chemicals can collide with pore walls, causing hydrocracking and carbon accumulation [7] Few elements of LB are transformed into volatile gases during LBC conversion, whereas the rest elements become carbonaceous products.


Fig 2: Preparation of lignocellulosic biomass

**2.1.1 Direct Carbonization**- Calcination and pyrolysis are included in the process of carbonization subjected to presence or absence of pyrolysis without oxygen. Pyrolysis is the simplest and most common method of carbonization due to its cost effectiveness and simplicity. Moreover, it produces material with large surface area and well-developed pores. Drawback lies in non-uniform morphology and high impurity content of biochar formed. Temperature plays an important role in determining the properties of prepared biochar [8]. Selection of appropriate pyrolysis temperature is needed for structure, applications and properties of LBC's. Study of pyrolysis rates is essential which influence physiochemical properties of biochar produced.

**2.1.2 Carbonization with Microwave Assistance:** Microwave assisted carbonization (MAC) bearing similarity with pyrolysis is a novel technique for preparation of biochar. MAC includes shorter processing time, reduced energy input and internal heating. MAC enables uniform heating with consistent chemical properties and controllability [9]. Compared to pyrolysis. Microwave electromagnetic wave field is known to improve the thermal degradation of biomass through selection, volume, rate, and heat [10], [11]. It is successfully used for production of biofuels and biochar's. The scaling up of MAC for commercial use is still a hurdle.

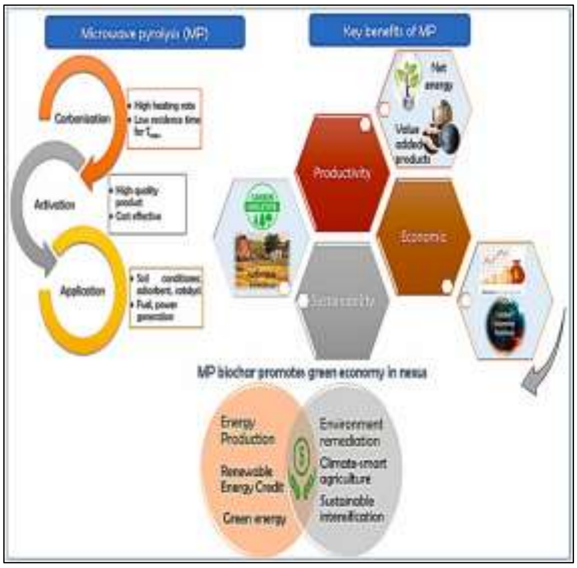


Fig 3: Microwave Assisted Carbonization

**2.1.3 Hydrothermal Carbonization**: In this process, LB is combined with water in a defined ratio and mild hydrothermal reactions occur under specific pressure conditions, water being active as heat transfer medium. Although HTC involves production of potential harmful components but biochar produced often termed as hydro char [12] exhibits better physical and chemical properties. This rapid pyrolysis method yields high surface area, abundant pores and biochar surface with rich functional groups with enhanced adsorption capacity [13].Among several advantages offered by HTC its main advantage is its ability of processing wet biomass without prior drying and carbon negative impact.

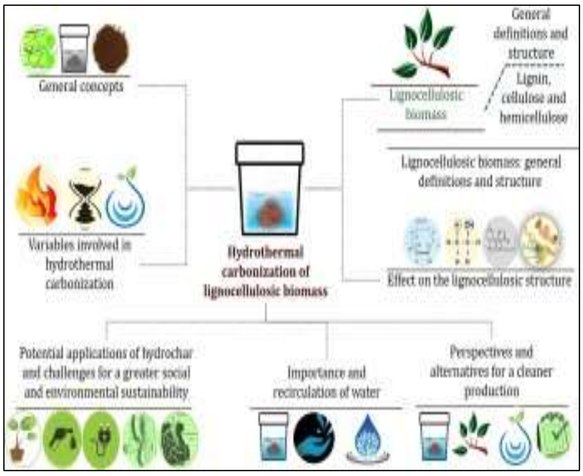


Fig 4: Hydrothermal Carbonization

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**2.1.4 Template-Directed Carbonization:** This process uses a substrate, such as a metal complex, micelle, or silicon dioxide, as a template to create biochar on its surface. The TDC process is more intricate, involving several intermediary steps and longer reaction times. Yet, the produced LBC has stable structure with more controllable pore size along with use of relatively inexpensive and readily available template [14]. TDC methods can be categorized in hard template and soft template carbonization methods [15]. Hard template process involves toxic chemicals with complex processes whereas soft template method is based on self-assembly of hydrophobic and hydrophilic molecules.

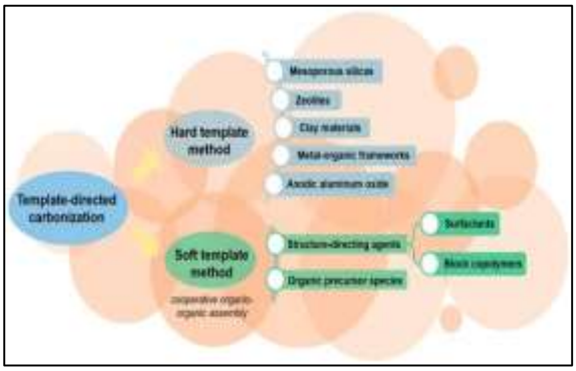


Fig 5: Template-directed carbonization

III. **ACTIVATION METHODS**-

The biochar produced often lacks substantial pore structure. Activation process is related with enhancement of pore density in carbonaceous material. It enhances the surface area of biochar and introduces functional groups on its surface [16]. Temperature and duration of activation plays a crucial role in structure and properties of activated product. Standard methods for activation include chemical, physical and physiochemical activation [17] .

3.1 **Physical Activation**: - Physical activation involves gaseous activation utilizing oxidizing gases like $CO_2$, water vapours and their mixes as activating agents, which partially oxidize biochar in the temperature range from $600^0$C-$1200^0$C. These gases work by etching and pore formation [18]. Recent researchers have explored the use of non-conventional physical activating agent. Physical activation has several advantages like simplicity, less pollution, etc. but suffer some drawbacks like long activation time, low yield and high-power consumption.

3.2 **Chemical Activation**; - In order to achieve impregnation and carbonization, an activating agent and raw material are mixed in a specific ratio. Potassium hydroxide (KOH), sodium hydroxide (NaOH), potassium carbonate ($K_2CO_3$), phosphoric acid ($H_3PO_4$), zinc chloride ($ZnCl_2$), sulfuric acid ($H_2SO_4$), hydrochloric acid (HCl), ferric chloride ($FeCl_3$) [19]. and other similar substances are commonly used activating agents. Selection of appropriate activating agent is crucial for preparing activated carbon as different activating agents significantly differ in their activation mechanisms. Same activations lack efficiency and direct conversion methods henceforth dual chemical activation strategy has become popular. For Ex: $MnCl_2$/KOH activation of banana peels [20] to produce biochar. Chemical activation suffers challenges of environmental impact, chemical recovery, equipment corrosion, recovery of chemicals etc.

3.3 **Physicochemical Activation**: - The hybrid approach of physicochemical activation makes use of the advantages of both chemical and physical activation techniques. The standard procedure for physicochemical activation permits biomass to be impregnated with an expanded surface area in contact with the activating agent. The activation of the activating agent is enhanced and a chemical reaction between the activating agent and the biomass is induced by heating the impregnated biomass again. The adsorption capacity of activated carbon with large pore size and excellent pore distribution is further enhanced by physical activation. The process of physicochemical activation often yields activated carbon with superior adsorption capabilities.

IV. **APPLICATIONS OF LBC'S**

Applications of LBC's is found in the field of industrial and domestic sectors. LBC's can be employed in petroleum refining, energy storage, pollution control, waste water treatment, [21] and catalysis. In addition to providing environmentally favourable and sustainable alternatives, their use aids in lowering dependency on conventional fossil fuels and mineral resources.

4.1 **Adsorption**: - Industrial waste waters are often loaded with heavy metal ions such as $Hg^{2+}$, $Zn^{2+}$, $Cr^{6+}$, $Pd^{2+}$, $Cd^{2+}$ etc. which even in low concentrations can lead to negative impacts on human health. Use of such water may lead to respiratory, cardiovascular, intestinal or digestive disorders along with some type of cancers. Heavy metals may be effectively removed from effluents using LBC because of its wide surface area, porous structure, surface active functional groups, and ease of availability. LBCs are employed to adsorb organic materials, colorants, odors, and inorganic chemicals from waste fluids in addition to heavy metals [22]. Wang et al. achieved a maximum clearance of 1100 mg/g by using biochar generated from bamboo [23] as an adsorbent to remove methylene blue dye from waste water. LBCs are employed in the sector of industrial gases to recover

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exhaust gases produced by industry and to eliminate offensive pollutants. Mukherjee [24]investigated the $CO_2$ adsorption behaviour of biochar produced from coffee grinds. To put it briefly, LBC is frequently employed as an adsorbent to absorb contaminants such as organic pollutants, heavy metal ions, exhaust gasses from industrial exhausts, and $CO_2$.

4.2 **Filler material**: - LBC find their application in the form of eco-friendly filler material for various composites like ceramics, thermoplastics, thermosetting materials etc. LBC's are added to composites [25] to enhance their mechanical, thermal, electrical properties. Compared to inorganic filler materials like glass or silica, they are a sustainable substitute. Because of its unique chemical structure, lignin can be used as a filler, stabilizer, compatibilizer, and reinforcement in composite materials. It is appropriate for a range of polymeric matrices with enhanced wettability, mechanical, and fire-retardant qualities because of its aromatic and cross-linked functional groups.

4.3 **Energy Storage**: - LBC's are used as electrode material for superconductors. The exceptional conductivity, consistent charge-discharge behaviour, and broad working temperature range of activated carbon generated from LB contribute to its increased specific capacitance. Reed residue wastes were utilized for super capacitor electrodes [26] . They pyrolyzed the biomass at various temperatures and found that carbon activated at $600^0$C showed outstanding electrical performance which was evaluated by cyclic voltammetry. Results obtained in various researches indicate high potential and application of LBC in energy storage.

4.4 **Catalysis**: - LBC along with excellent carrier properties also exhibits favourable properties like stability at high temperatures, acid & alkali corrosion resistance, easy separation of components. Along with presence of functional group on surface, high porosity and surface area also influences catalytic ability of LBC. Catalytic activity of LBC is also influenced by the source of LB and condition under which it is activated. Jiang et al produced catalysts using corn stalks-based biochar and surface area of these products were ranging from $1120m^2/g$ to $1640\ m^2/g$. [27] These catalysts were reusable and used in hydrothermal degradation of lignin. In other research works LBC's were also found to be effective in tar removal [28].

4.5 **Fertilizers**: - LBC can also be used to raise crop yields, encourage plant growth, and improve soil fertility. Their behaviour makes them perfect for use as slow-release fertilizers in soil, releasing organic carbon and important nutrients (including N, P, and K) gradually. The complex polymer known as lignocellulosic biomass, which is made up of cellulose, hemicelluloses, and lignin, is a promising feedstock [29].Additional compounds found in varying amounts include proteins, oils, pectin fractions, sugars, and other nitrogenous elements, as well as ashes, chlorophyll, and inorganic waste [30], [31]. The primary component of biomass is lignocellulosic material, which is obtained from forest and agricultural waste [32], [33]. The species, growth phase, and season are among the variables that affect the content of lignocellulose in biomass [34]

## V. **CONCLUSION**:

Temperature has a significant impact on the creation of primary products and by products in direct pyrolysis procedures. Additionally, the type of feedstock, reaction environment & pyrolysis conditions are vital factors in production & composition of LBC. Hydrothermal carbonization methods offer advantage over traditional pyrolysis methods such as enhanced calorific value and increased surface functionalities with challenges like reduced selectivity and formation of by products .MAC technique needs to be scaled up to commercial level. TDC can balance stability and pore structure, but it is only useful in certain situations and has limitations that need to be investigated further.

Template method which is a novel method can be a favourable choice. In terms of activation methods physical, chemical methods, their combination and dual chemical activation methods are promising methods to increase pore volume. Moreover, applications of LBC in more fields needed to be explored beside adsorption, catalysis and field of energy storage.

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