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Review Article

A Review of Green Technologies for Cellulose Extraction from Lignocellulosic Biomass: Pretreatment Methods and Applications

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ABSTRACT

The majority of the material called lignocellulose biomass (LCB), a type of plant biomass, is made up of these three compounds. The most common polymer to break down on Earth is cellulose, which is very useful and has many uses. Because cellulose is securely linked to the compound's hemicellulose and lignin in lignocellulosic materials, it is highly challenging to separate the material from LCB components; therefore, effective pretreatment techniques are required to make the material separation easier. Green pretreatment approaches have been proposed as a gentler and more environmentally responsible way to address these problems. When assessing these green processes, a variety of factors are taken into account, such as the effectiveness of delignification with a lower solvent demand, the impact on the environment, the economic feasibility, and the suitability for new sustainable processing solutions. We also assessed how using biomass affected land use, production of greenhouse gases, and group effects, among other socioeconomic and environmental factors. This paper examines the challenges, ongoing research, and recent developments in effective biomass-based energy systems to increase energy output while lowering environmental concerns. Additionally, it provides a summary of how cellulose is separated from various lignocellulosic biomass using sustainable and green methods.

1. INTRODUCTION

The Economic problems are now a major global problem as a result of growing energy consumption, finite fossil fuel supply, and environmental concerns. This study looked at how serious the global energy problem is and stressed the need for sustainable energy solutions [1]. Statistical data shed light on the current energy scenario and the need for immediate action. In 2021, there was a 4.6% growth in primary energy demand, which resulted in a rise in global utilization of energy driven by growing economies like China and India [2]. About 80% of the fuel used in 2020 will come from natural gas, coal, and petroleum,

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which will keep monopolizing the global energy mix. Although coal stocks could persist for centuries and oil reserves for fifty years, there are worries that fossil fuel deposits are limited [3]. Furthermore, using fossil fuels releases greenhouse gases at record levels; in 2019, the global CO_2 output reached 36.8 billion metric tons. There has never been a greater urgency to cut emissions and make the switch to low-carbon opportunities. Biomass, wind, hydroelectricity, solar power, and thermal power are examples of renewable energy sources that have become competitive alternatives to fossil fuels [4]. To fight climate change, reduce dependency on fossil fuels, and achieve energy security, governments, lawmakers, and international organizations are working harder to promote the growth of green energy sources. In 2021, 29% of the world's electricity was produced by hydropower, the greatest renewable energy source, which was followed by solar and wind. As more people become aware of the possibilities of renewable energy technologies, investments in these technologies have been increasing [5]. Therefore, understanding the global energy landscape is crucial for assessing the role of biomass together with other renewable energy sources that are renewable in the quest for a more sustainable and greener future [6]. Any organic substance derived from microorganisms, plants, or animals is referred to as biomass. It can come in a variety of forms, including organic waste, wood pellets, renewable energy, and agricultural waste [7]. The energy produced when biomass is transformed into fuel that is liquid, heat, or electricity, however, is known as power from biomass. However, the capacity to use organic matter, its steady energy supply, and its simplicity in integrating into existing infrastructure for an effortless conversion to renewable energy are some of the benefits of biomass over other forms of sustainable energy [8]. Biomass energy is produced using a variety of conversion technologies and methods. One common method is biomass combustion, which uses burning organic materials to generate electricity and heat. Anaerobic digestion breaks down organic waste to produce biogas. The Fischer-Tropsch process or pyrolysis are other methods for turning cellulose into liquid fuel [9]. Using a catalytic chemical method called the Fischer–Tropsch technique, syngas—a mixture of carbon dioxide and hydrogen monoxide is converted into liquid hydrocarbons like petrol and diesel. This other method of converting biomass into liquid fuels could not directly involve pyrolysis. Depending on the specific feedstock and intended result, peak temperatures to feed this process typically range from 400 to 600 °C [10]. Syngas, which is created when feedstock is heated through gasification, can be used as a substrate to produce chemicals and biofuels, for heating, or to generate power. [11] have investigated the microbial process of fermenting pyrolysis, gasification, the burning process, and enzymatic hydrolysis processes. Thermochemical reactions that occur at low temperatures (below 300 °C), in addition to elevated temperatures (over 300 °C), include gasification, combustion, and pyrolysis. Because it can function at temperatures as low as 500 °C, and this is believed to be much lower than the gasification temperature range of 800–1300 °C, pyrolysis is one of the most promising and widely utilized processes. Recorded the process of pyrolyzing coconut waste to create renewable electricity. Biomass energy has grown in importance for several reasons. First, biomass is considered to be renewable energy since it may be substituted by organic processes like the growth of plants and trees [12]. It is not the same as fossil fuels, which are scarce and contribute to environmental problems like climate change. Second, because the CO_2 absorbed after biomass growth balances the CO2 released after biomass burning, employing biomass energy leads to net-zero greenhouse gas emissions [13]. The Global Renewable Energy Agency (IREA) estimates that a 12% reduction in global energy-related CO_2 emissions would occur if the share of renewable energy were doubled by 2030. Emissions of greenhouse gases are effectively reduced by biomass [14]. Additionally, biomass energy reduces the production of greenhouse gases and pollutants through landfills by converting organic waste into useful energy. Soybean dregs can be utilized to make nitrogen-rich carbon porous materials containing nitrogen concentration that is up to 4% and a range of nitrogen forms, according to a study by Liang-Nian. With nitrogen-containing groups as well as ultra-micropores, the materials' exceptional CO_2 absorption capabilities were 6.3 and 3.6 mmol/g, for example, at current air pressures of 0 °C and 25 °C [15]. It has been demonstrated that the

materials have a high capacity for adsorbing CO_2 from biomass that has been hydrothermally carbonized (HTC), producing char or pyrolyzed biomass. With nitrogen-containing groups as well as ultra-micropores, the materials' exceptional CO2 absorption capabilities were 6.3 and 3.6 mmol/g, for example, at current air pressures of 0 °C and 25 °C [16]. It has been demonstrated that the materials have a high capacity for adsorbing CO_2 from biomass that has been hydrothermally carbonized (HTC), producing char or pyrolyzed biomass. This study demonstrates the potential of biomass as a sustainable and environmentally friendly power source by examining the different ways it may be used to generate green energy [17]. By examining several biomass conversion techniques, including combustion, anaerobic microbiological digestion, a process known as and thermal gasification.

Our goal is to provide a thorough understanding of the part biofuels play in the shift to a greener energy landscape. The societal, financial, and external advantages of using biomass are also covered in this review study, with a focus on waste reduction. In order to address the most pressing issues facing our energy system, we hope to encourage more research, the development of new legislation, and the widespread utilization of biofuel-based techniques by showcasing the diverse applications of biomass towards environmentally friendly energy [18].

2. UTILIZING BIOMASS TO GENERATE RENEWABLE ENERGY

The potential for using different biomass sources to produce clean, renewable energy is immense. By utilizing the potential of energy crops, agricultural waste, urban garbage, and wood waste, we can reduce the environmental impact of traditional energy sources and our dependency on fossil fuels. Using biomass to generate green energy is not only a sensible choice; however, it also opens up possibilities for effective waste management, agrarian development, and the transition to a more sustainable and economically viable future. This is a summary of the various plant matter feedstocks, such as organic urban waste, forestry materials, energy crops, and agricultural residues [19].

2.1 Forestry trash

A lot of fire or being abandoned by forestry debris can lead to environmental contamination, but forestry trash, which includes sawdust, bark, tree tops, and branches, is a byproduct of logging and forest maintenance and can be used as biomass feedstock for some processes, which involve the synthesis of wood-based products, biofuels, and warmth and power. Birch and bamboo bark have been converted for the production of biofuel and green power [20]. There are several methods for processing and creating biofuels from crop residues that farmers around the world produce. These techniques include chemical therapies (transesterification, for instance), biochemical transition (microbial fermentation, hydrolysis using enzymes, including anaerobic digestion), as well as hydrothermal liquefaction and thermal conversion (gasification, pyrolysis, and combustion) [21].

3. ORGANIC WASTE FROM MUNICIPALITIES

Green municipal garbage, sometimes referred to as organic material, is biodegradable debris produced by residences, eateries, and other businesses that generate organic waste. For example, scraps of food and organic matter can self-digest and be transformed into biogas, a methane-rich green energy source; waste from gardens and green rubbish can be composted to create nutrient-rich soil amendments. Instead of ending up in landfills, these innovative methods transform organic waste from the city into valuable energy sources [22]. Agricultural waste, wood waste, and paper are all possibilities as combustible materials in

biomass heating systems to generate electricity and heat. In order to lessen landfill waste and help create a cleaner, more ecologically friendly energy future, communities can harness the energy potential of organic municipal waste [23].

Table 1: Generating renewable energy from biomass resources derived from agricultural waste [24].

Agriculture waste	**Description**	**Potential uses in green energy production**
Sugarcane Bagasse	Fibrous residue after juice extraction	Combustion for electricity, bioethanol production, and briquettes for fuel
Coconut Shells	Hard shells remaining after extracting the coconut meat	Pyrolysis for biochar and bio-oil, gasification, and solid fuel briquettes
Fruit & Vegetable Waste	Spoiled or leftover produce from farms/markets	Biogas through anaerobic digestion, bioethanol via fermentation
Palm Oil Residues	Empty fruit bunches, palm kernel shells	Combustion, pyrolysis for bio-oil and biochar, biogas
Corn Stover	Leaves, stalks, and cobs left after corn harvest	Cellulosic ethanol, anaerobic digestion for biogas, pyrolysis for bio-oi
Rice Husk	The outer shell is separated from rice grains during milling	Combustion for electricity, gasification for syngas, biochar via pyrolysis

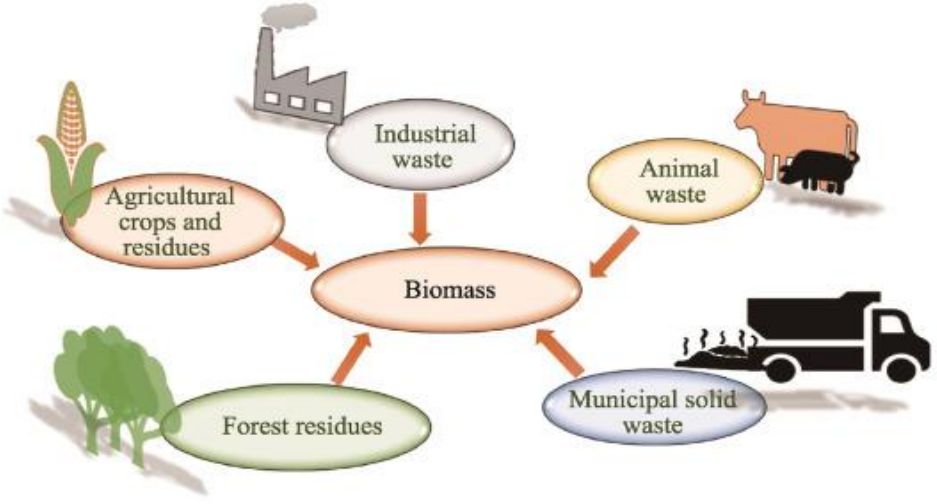


Fig. 1. Utilizing forest trash to generate sustainable energy [25]

3.1. Municipal and industrial waste

Garbage produced in metropolitan areas, including garbage from homes, businesses, and the lignocellulose food sector, is referred to as municipal waste, or municipal solid waste (MSW). Carbon waste, cardboard, leftovers from meals, garden debris, and textile waste are just a few of the many elements that are included in municipal waste. The food industry, in instance, produces a lot of waste, including different residues and by-products that may be utilized as cellulose sources [26]. Cellulose can be made from leftover veggies and fruits, like potatoes with carrot peelings and other leftovers, and additionally from pomace, which comes from grape skins themselves, apple hard pomace, and citrus peels, which are used to make fruit juice and alcohol. Others include grounds of coffee, a by-product of coffee, leftover grain from the whisky and brewing industries, and dairy waste like whey, which has a trace amount of cellulose. Making use of items that would otherwise be discarded enhances sustainability, lessens environmental effects, and saves trash disposal costs. The viability of cellulose extraction from food industry waste, however, might vary depending on a variety of parameters, such as the type of materials, the processing techniques employed, and the necessary level of cellulose purity [27].

3.2. Woody biomass

Woody biomass is defined as biomass derived from woody resources such as forest residues, sawmill waste, and trees. Ninety to ninety-five percent of all pulp with cellulose is made from woody biomass, becoming the most prevalent organic resource on Earth and the basis of renewable energy. Whichever species of tree, the three forms of lignin may have different compositions[28]. Other polysaccharides, such as xyloglucan and pectin, may also be present in wood, depending on the tissue's age and composition. While ash comprises almost all of the basic components of wood, extractives such as phenolic compounds, including stilbenes, or tannins, flavonoids, and terpenoids, steroid injections, lipids, and waxes are negligible wood constituents. Forest leftovers, limbs, tools, and leaves, as well as other hardwood materials from plants living in a real forest, forest habitat, or rangeland habitat, are all considered woody biomass [29]. Woody biomass can also be obtained directly from hardwoods or indirectly through the collection and preparation of wood. The two types of woody biomass are hardwood, or trees with leaves that fall, and softwood, as their main or coniferous vegetation. Hardwood typically has less lignin and more cellulose and hemicellulose, while softwood has more extractives, such as resin. Biofuels can be produced from wood's cellulose and hemicellulose, which are renewable sources of carbohydrates [30].

3.3. Non-woody plant matter

Non-woody plant matter is the term used to describe all lignocellulosic biomass sources other than wood-based organisms. Based on where they come from, non-wood products containing cellulose are divided into three primary groups: energy crops, lignocellulosic manufacturing, municipal waste, and agricultural leftovers (Fig. 2). Non-woody biomass has a high yield and a lot of applications as a feedstock for cellulose synthesis [31]. Examples of specialized renewable energy sources with the benefits of rapid growth, high cellulose content, and environmentally friendly growing potential are switchgrass and miscanthus. Using non-wood biomass like lignocellulose to create cellulose has several advantages, including being affordable, accessible, and plentiful, as well as lowering the amount of waste that is generated by landfilling or incineration [32].

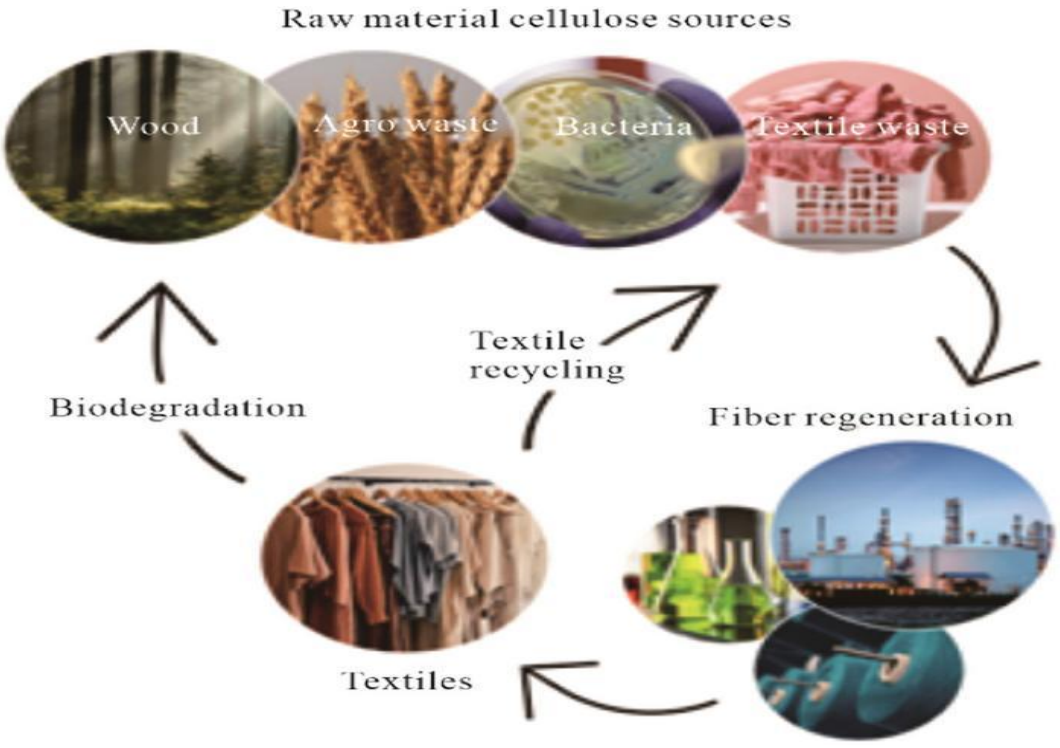


Fig. 2. Non-wood Cellulose's sources [33]

4. TECHNIQUES FOR REMOVING CELLULOSE FROM LIGNOCELLULOSE BIOMASS

Cellulose extraction is the process of removing ethanol from the outside of plant cell walls, where it coexists with other substances, mainly lignin, along with hemicellulose. Numerous technological, physicochemical, and biological pretreatment methods have been used to extract cellulose from complex lignocellulosic biomass matrices. The cellulose extraction process can be affected by a wide range of elements, including the source material, pre-treatment methods, solvent selection, temperature and pressurization, extraction length, mechanical agitation, pH control, particle size, solid-to-liquid ratio, post-treatment, and washing [34]. These elements, which must be properly managed and optimized, determine the effectiveness and caliber of cellulose extraction. Depending on the type of production, the source of the biomass, and the desired cellulose quality, several procedures may be used to extract cellulose from lignocellulosic biomass. Numerous techniques for separating cellulose from lignocellulose biomass have been thoroughly studied, and some of them have been patented (Table 2). However, most methods consist of three main steps: pretreatment to remove lignin and hemicellulose, filtering or sterilizing to remove any lignin that remains, and conditioning of the biomass and hemicellulose [35]. Reduction of size, refluxing methanol as well as deionized water to eliminate extractives, and drying, shifting, from washing to eliminate dirt and pigment matter are all steps in biomass conditioning. Two advantages of biomass conditioning are that it improves the surface area available for additional chemical, microbial, and enzyme reactions while also reducing the lignin barrier. To create cellulose fibers, the dried biomass is sometimes prepared for drying after biomass conditioning to solubilize the two components. Table 4 illustrates how cellulose is extracted from various lignocellulose sources. The most often used pre-treatment techniques for biomass are bleaching with ozone or peroxide, pulping with acid or alkali, and others [36]. Cellulose undergoes additional bleaching processes to eliminate colored lignin and broken-down components from

cellulosic wastes. Bleach chemicals that include hypochlorite, including peroxide, are used to oxygenate water-insoluble lignin to break certain bonds and produce water-soluble molecules, including carboxylic acid derivatives and aromatic aldehydes. By severing the connections that hold lignin and hemicellulose together, bleaching chemicals facilitate the removal of both materials. Usually, the bleaching procedure is carried out on several occasions until a white fibrous material is produced, signifying that the procedure for bleaching was effective [37].

Table 2. A few patented techniques for extracting cellulose [38].

Number of patents	The invention's title	Methods of extraction that are patented	Synopsis of the newly developed technique	Findings from the invention	Type of biomass	Year
A1 (US20160130369)	This process of lignocellulosic biomass (low lignin biomass) for the manufacture of cellulosic ethanol and chemicals	Autohydrolysis, or steam explosion without a catalyst	Biomass was exposed to water at 170 °C to 220 °C with 100 to 322 Psi for 2 to 300 minutes without the incorporation of mineral acid catalysts in order to achieve a severity index of about 4.0. The cellulose fiber is separated from the liquid portion by centrifugal filtering, compressing, and drying.	A lignin-free solution containing 87% sugars as dissolved solids, including 63% Xylo oligosaccharides (w/w), has been generated on a dry matter basis.	Miscanthus, switchgrass, prairie greenery, sorghum bagasse, including sugar cane bagasse, maize stover, wheat straw, and corn cobs.	2012
US8979961B2	Method for extracting cellulose from lignocellulosic biomass	Acid hydrolysis using dilute sulfuric acid	Biomass is treated with diluted sulfuric acid under controlled conditions to hydrolyze hemicellulose while preserving cellulose fibers. The mixture is neutralized, and cellulose is separated and purified.	High-purity cellulose (>95%) obtained with effective lignin removal.	Wood chips, Agricultural residues.	2014
The US20160201102A1	Procedure for Lignocellulosic Biomass Enzymatic Conversion.	Hydrolysis by enzymes	A combination of cellulase, as well as the cellulose and/or hemicellulose in the processed biomass are partially hydrolyzed by hemicellulose enzymes. The feedstock that has been partially hydrolyzed is then mechanically treated.	N/A	1N/A	2014

4.1. Cellulose derivatives

A family of compounds known as cellulose derivatives is created by adding different chemical groups, including hydroxyl groups, to cellulose to change its chemical structure and provide particular qualities or

functions [39]. The hydroxyl (-OH) groups that make up the carbohydrate units—which are found at the C2, C3, and C6 positions around the glucose rings—are the primary sites for derivatization. Such as cellulose and the reagents that add the required functional groups undergo chemical reactions to produce cellulose derivatization [40]. Cellulose polymers and cellulose esters are examples of common cellulose derivatives. The method of making cellulosic derivatives. Such as cellulose ethers are ethyl cellulose (EC), methylcellulose (MC), sodium carboxymethyl fiber (NaCMC), carboxymethyl cellulose (CMC), the compound hydroxypropyl methylcellulose (HPMC), hydroxyethyl cellulose (HEC), and a material called HPC. The great majority of cellulose-containing ethers dissolve in water; some examples of cellulose esters are cellulose acetate, also known as cellulose ester butyrate (CAB), cellulose nitrate, and cellulose propionate [41].

5. ETHERS OF CELLULOSE

5. 1. Carboxymethyl cellulose

Carboxymethylcellulose (CMC) is a water-soluble, anionic cellulose ether derivative that contains alkaline cellulose and chlorine acetic acid or its sodium salt. The processes of etherification and mercerization yield carboxymethylcellulose. In etherification, alkali-cellulose must be converted to CMC using sodium chloride, also known as chloroacetate (SCA) or chloroacetic acid (CAA). Cellulose and an alkali react during mercerization to form alkali-cellulose and water. When carboxymethyl groups are exposed to the cellulose backbone during the etherification process, CMC is produced. After filtering out any remaining alkaline, the resulting mixture was neutralized to stop the process [42]. Among the purification methods that can be used to produce a pure CMC product are filtration, washing, and centrifugation. The previously purified CMC is typically crushed into a fine powder as well as a granular form after drying to remove excess moisture. because carboxymethyl ionic bonds are provided to the cellulose chain by CMC. In contrast to uncooked cellulose, it always dissolves in water, which hydrates the molecule. A vast array of industrial products, such as paper, detergents, glues, adhesives, ceramics, cosmetics, and food, contain CMC [43].

5.2. Hydroxypropyl methylcellulose

Hydroxypropyl methylcellulose is derived from the natural polymer cellulose. The free-flowing, white to almost off-white powder known as hydroxypropyl methylcellulose can be fibrous or granular and has no taste or aroma. The solvent of methylcellulose, HPMC, is a propylene glycol that is created by reacting the partially depolymerized methyl group using a very small amount of hydroxypropyl substitution [42]. It is an adaptable nutritional component used in food production and has FDA as well as EU approval for usage in direct and indirect food. By substituting hydroxypropyl groups for the inevitable hydroxyl groups in blood sugar, HPMC proceeds through methyl substitution. The cellulose backbone's viscosity, soluble content, gelation analyses, and film-forming qualities are all improved by these changes. Applications for HPMC polymer are numerous and include oil recovery from petroleum reserves, food, textiles, and healthcare. It has also been studied as a superior biofilm for use. But it is more commonly used to make pills and tablets in the pharmaceutical business [43].

5.3. Cellulose esters

To create cellulose esters, cellulose must be chemically modified by substituting ester functional groups like acetate, butyrate, or propionate for part of its hydroxyl (-OH) groups. The process involves swelling cellulose in a solvent like acetone, dimethylformamide, or dimethyl sulfoxide (DMSO) so as to activate it and increase the amount of hydroxyl groups that are available for esterification [44]. To facilitate the

esterification process, the activated cellulose is combined with an esterifying agent (such as acetic anhydride) and a catalyst (such as sulfuric acid alongside a Lewis acid reaction, such as zinc chloride) at 60 to 80 college degrees Celsius. The resultant mixture is then processed to eliminate any leftover contaminants and surplus reagents; filtering or centrifuging may be necessary for the purification of the cellulose ester following a solvent wash. A base, such as magnesium hydroxide or sodium bicarbonate, is used to neutralize any residual acid catalyst [45].

5.4. Cellulose derivatives application

The manufacturing and use of cellulose derivatives, which are highly significant commercial products for a variety of industrial and household applications, include protective coatings, laminations, optical movies as absorbents, and as additives in construction, food, medicine, and cosmetic products [46].

5.5. Hydrogel for drug delivery and biosensors

Because of their inherent and distinctive encapsulation/binding properties, cellulose-based viscoelastic excipients have been thoroughly studied for a range of medical applications. A large amount of water can be absorbed and released by the hydrogels, which are dimensional chains of hydrophilic, meaning crosslinked macromolecular cellulose. They are used as biomaterials for tissue engineering, cell carriers, drug delivery vectors, and biosensors. The hydrogels can be used with injectable hydrogels and other continuous drug delivery methods [47]. Chewing, drug management, transdermal drug absorption, and optical drug delivery because of their porosity, which permits controlled and extended drug release. They can lower adverse effects, keep bloodstream drug concentrations stable, and stop the gastrointestinal breakdown of sensitive medications. Intravenous cell wall hydrogels serve the purpose of localized drug delivery because they may be loaded with therapeutic compounds and injected into specific target locations throughout the body. For controlled medicine absorption for eye disorders, including glaucoma or bacterial infections of the eyes, they can also be created as eye drops or glasses [48].

5.6. Packaging for food

Because of its low density, mechanical qualities, availability, reinforcing qualities, and biodegradability, nanocellulose is a fantastic choice for processing polymer compounds for applications related to food packaging. Polymeric materials for packing food can also be made with it. Because of their potent antibacterial properties and resistance to moisture and gases like carbon dioxide and oxygen, many thin composite films containing nanofillers find extensive use in food coating and packaging [49]. CNCSO3H was produced by pretreating wood pulp with sulfuric acid (H2SO4), CNCCOOH was produced by pretreating cotton linters with ammonium persulfate (APS), and CNCCOOH and CNCSO3H were treated with an ester to create CNCCOOR. A comparison is made between the properties of gas barriers in plastic films, including PLA, PET, PE, and PP. Finally, laminated film (P-CNC-P) was submitted to gas permeability investigations at 23 °C and 50–80% humidity percentages. The oxygen susceptibility rose by 90–100% during lamination [50].

5.7. Treatment of wastewater

In water treatment processes, they can be employed as flocculants, adsorption agents, and membranes used for separating water and oil (Peng et al., 2020). Research indicates that cellulose-based polymers, such as nanocellulose, are not very effective at treating wastewater, removing oil, and sometimes heavy metal ions. Because of its unique properties, nanocellulose is a great material for removing harmful chemicals from liquid waste. Claim that nanocellulose can also be utilized to create membranes with remarkable performance and adjustments for high-pressure applications such as water treatment, the removal of environmental contaminants, and the purifying of drinking water systems in residences and commercial

buildings [51]. CNCs have occasionally been used as absorbents to extract heavy metals from waste. Evaluated the flocculation results of three nanocellulose-based anionic sulfonated flocculants with varying charge densities in comparison to a commercial coagulant. Even though they used a lot fewer chemicals than copper sulfite coagulation, the researchers discovered the levels of turbidity and COD removal capacities of nanocellulose-based anion-based decreased flocculants were comparable to a marketed reference polymer at low concentrations [52]. The flocs created using nanocellulose flocculants were smaller and rounder than wastewater flocs made with the available reference polymer, but the anionic nanocellulose microfiber flocs were more stable. This demonstrates how heavy metals can be removed from drainage using flocculants based on nanocellulose [53].

5.8. Environmental hazards

Without adequate treatment, by-catch, process waste, and aquaculture and process effluents are disposed of, posing serious environmental risks and significant financial expenses. Diminished oxygen levels at the marine bottom, the burying or suffocation of living things, and sickness are all consequences of the practice of the underwater disposal of bycatch (E. P. A. US, 2021). Putrefaction of seafood discards in landfills might affect climate change due to the generation of methane (CH4), ammonia (NH3), and hydrogen sulfide compounds, greenhouse gases (GHGs) such as oxygen and carbon dioxide (CO2). Emissions of green, CH4, and nitrous oxide are much higher for landfills than for composting [54].

5.9. Economic and environmental factors

The potential of biomass energy to lower greenhouse gas emissions when compared to conventional fossil fuels is a significant feature. Carbon dioxide (CO2) is released into the atmosphere when biomass is burned, even though all of the carbon released is a natural component of the ecosystem's carbon cycle. This implies that the carbon monoxide which living things take in during growth balances the carbon produced during combustion. Since this approach doesn't increase atmospheric CO2 levels, it can be regarded as carbon neutral as long as the bioenergy is sourced responsibly [55]. However, the zero-carbon footprint of biomass energy is called into question due to issues with deforestation, adjustments to land use, and inappropriate extraction techniques. Maintaining carbon neutrality requires sustainable sourcing and finding a balance between regeneration and consumption. Biomass energy has negative environmental effects even as it reduces greenhouse gas emissions. Among the components emitted during incineration that have an impact on air quality and human disease are particulate matter, carbon dioxide, nitrogen oxides, and other volatile organic compounds [56]. Mitigation strategies include tighter emission limits, more sophisticated conversion technologies, and contemporary air pollution control devices such as scrubbers and electrostatic precipitation systems. Numerous factors, including cost, pricing, construction, technical development, and government support, affect the economic feasibility of biomass energy [57]. To ensure that biomass thermal energy facilities comply with all applicable environmental standards, routine compliance testing and monitoring are required. In resource-rich regions, it can be competitive and economical for biomass producers, removing reliance on imported petroleum and diesel.

However, there may be substantial facility and initial setup costs associated with collecting and transporting biomass, and changes in the cost of nearby energy sources may have an effect on the economic viability of biomass [58]. A number of elements must be taken into account in order to comprehend the economic reality of producing power from biomass. As technology advances, it is anticipated that the cost of producing biomass energy will decrease, increasing its attractiveness from a socioeconomic perspective over time. By providing feedback on tariffs, subsidies, rebates, financial guidance, and renewable energy targets, governments can encourage the production and investment of biomass. Furthermore, in order to boost the usage of biomass energy and maintain competent development, supportive norms and regulations are required [59]. The key components that determine the system's viability and economic structural

integrity are depicted in the following figure. To investigate and mitigate the impacts of biomass energy generation, stringent measures are required. These regulations ought to focus on emission reduction, sustainable sourcing, and land-use plans that protect biodiversity and stop deforestation. International cooperation and agreements facilitate the exchange of best practices, guaranteeing the moral application of biomass energy on a global scale [60].

6. CONCLUSION

The utilization of renewable biomass as a source of renewable energy and its potential future applications are examined in this thorough research. Biomass has great promise as an alternative to fossil fuels to reduce greenhouse gas emissions when it is gathered responsibly. Both solvents are capable of selectively dissolving the hemicellulose in biomass without compromising cellulose. The most common of the fundamental pre-treatment procedures for biomass is mild pretreatment since it may efficiently remove a sizable amount of lignin and hemicellulose. This makes cellulose more accessible and facilitates its conversion into useful products. This review looks at current research, challenges, and advancements in efficient biomass-based energy systems, as well as sustainable feedstock for the extraction of cellulose because of its affordability and accessibility. To get over the drawbacks of some of the extraction techniques used today, Future studies should focus on creating an economical and sustainable fractionation method that can be scaled up and ensures the production of excellent quality cellulose without sacrificing yield.

Authors' contributions:
Muhammad Asif: worked on the manuscript. **Arshad Ali:** improved overall paper mistakes. **Abdul Ghaffar:** work on the table and figures.**Namatullah:**set the paper formatting and carefully checked it for errors.**Mohammad Siddique:** Work on the abstract and conclusion. **Saadatullah khan Suri:** removed plagiarism. **Muladad:** did the setting of the paper overall. **Anwar Khan:** Solved grammar mistakes.

Conflicts of Interest

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