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Research Progress and Prospects of Platform Chemical Production from Straw-Based Biomass

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Abstract. The excessive reliance on fossil fuels since the start of the Industrial Revolution undoubtedly poses a major challenge in terms of both energy security and environmental protection. Against this background, widely available, renewable and carbon-neutral wood pulp (particularly straw) is considered to be a feasible alternative to fuel, chemicals and materials. But the 3D network of cellulose, hemicellulose, and lignin through complex chemical links is a key obstacle to efficient bioconversion. This article gives a systematic review of the latest progress in the field of high-value utilization of straw, especially its micro-structural change, its interactive mechanism, and its structural and activity relationship. In reaction engineering, we study the influence of pre-treating, catalytic and improved technology on the realization of distinct separating and conversion of components, and evaluating their performance in biodegradable materials, microchemicals, and closed-loop farming. Although progress has been made in the area of catalyst design, process integration, and other areas, the current research focuses on a significant deficiency in micro-mechanisms, side effects, synergistic interactions between multiple components, as well as the overall economic benefits of the process. Clearly, the focus will be on developing efficient and low-cost pretreatments, clarifying key pathways, designing powerful catalysts, and integrating different technologies into systems to push the process forward from laboratory to industry.

Keywords: Straw-Based Biomass, Platform Chemicals, Biomass Conversion, Catalytic Systems.

1. Introduction

The rapid development of the world economy is largely dependent on fossil fuels. Based on these data, global total energy consumption reached 418 EVs in 2019, with a projected increase of 23 per cent to 516 EVs by 2040. Of this, over 80% of energy comes from fossil fuels such as oil, coal or gas [1,2]. This unsustainable arrangement of energy sources raises two issues: on the one hand, the scarcity of fossil fuels on the other, on the other hand, the increasing mismatch between the constant depletion of these resources and the sharp increase in consumption demand, which has led to widespread international energy safety issues [3-5]. Secondly, large-scale exploitation of coal has resulted in severe environmental problems. These include the massive emissions of carbon dioxide and the resulting global warming and warming, as well as ozone depletion, air and water pollution

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caused by pollutants such as sulfur and heavy particulate matter, excessive PM2.5 and acidic rain, all of which are important [6-11].

In response to these problems, the international community has entered into a series of agreements that actively promote the transformation of the energy mix. The Chinese government has also put forward ambitious Carbon Cap and Carbon Neutral goals aimed at optimizing its energy mix and promoting a low-carbon and sustainable economy [12,13]. Against this background, finding and developing sustainable, renewable and clean alternatives to fuel, chemicals and feedstocks is currently a global consensus and an urgent scientific and industrial priority [14-18]. This strategy is not only essential for resolving energy crisis and ensuring security of energy supply, but also for combating climate change and achieving social sustainable development.

As one of the most abundant CO resources in the world, lignocellulosic biomass is regarded as a good alternative to fossil fuels. Of those resources, due to their wide availability, relatively low cost and "carbon neutral" characteristics, agricultural residues are essential for building a sustainable bio-refinery system [5,9,16,19]. They are valuable because of their particular chemical properties: they can be converted from cellulose, semicellulose and lignin into highly value-added products [6,8,12,13]. However, translating this enormous potential into actual industrial use is a big challenge given its physics and chemistry. Cellulose, hemicellulose, and lignin interweave into complex covalent bonds (e.g., lignin-carbohydrate compounds, LCCs) and hydrogen bonds within the stalk's cell walls to form a solid three-dimensional non-degradation [1,6,9]. structure. This inherent "resistance" is one of the most critical constraints for the conversion of the biomass, which severely hinders the access of the enzyme or the chemical catalyst to the target component, resulting in low conversion efficiency and very costly [3,11,15].

Therefore, the focus of this research has shifted from merely recognizing its value to dealing effectively with this entrenched architecture. Clearly and effectively separating the three major components from each other, coupled with a synergistic decoupling policy, is crucial for exploiting the full potential of straw and successfully substituting fossil fuels.

Although certain progress has been made on the structural degradation of biomass, such as acid, alkali, physical and water treatment, there remains a significant lack of knowledge on how to achieve efficient utilization of all components, thus significantly restricting the industry of lignocellulose.

Initially, it is generally difficult for existing methods to achieve an effective separation and effectively suppress undesirable effects during the pre-treatment phase and in the separation of components. When the lignin is detached, for instance, it is particularly easily condensed, which reduces the reaction and makes the subsequent depolymerisation extremely difficult. In addition, it is highly likely that pulp will be over-degraded under heavy or strong alkali conditions [4,9]. So far, we have little understanding of micro-mechanisms on the macro-level, especially on the precise molecular mechanisms associated with LCC bond cleavage and lignin fragmentation, which require further clarification [1].

At the time of the conversion of the catalyst and the control of the product, there are many problems that need immediate attention. Generally speaking, the performance of the catalytic converter is poor: issues such as the relatively low recovery ratio (for example around 30%) and many by-products are common when converting pulp into chemicals such as HMF. There is therefore a pressing need to develop more efficient catalysts and to clarify specific pathways for reaction [20]. Moreover, there is still insufficient research on the extraction and efficient conversion of levulinic acid, and there is still insufficient research on bimetallic catalysts (such as

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hydrogenation) for their downstream reactions. In particular, it is necessary to systematically examine how the metal fraction affects the characteristics of the catalyst [10,17,21].

How this response works is not yet fully understood: there are still significant gaps in the regulatory mechanisms for side effects (such as polymerization and aldol condensation), as well as the rearrangements of the ring-opening pathways for the conversion of substrates such as furfural [2]. Building more carbon-intensive products through CCS is an essential component for the improvement of the entire value chain, but specific modalities for achieving this continue to be a core theme of current related research [14].

Moreover, there is insufficient interaction between several components: most existing research focuses primarily on optimising single components or producing single products, while neglecting co-generation and cross conversion of a platform molecule like hemicellulose or cellulose HMF. This is not making full use of all biomass components, leading to certain wastage of resources [8].

How to combine high-efficiency pretreatment, precise catalytic conversion, and economical separation into a comprehensive and economical process of biological purification is a major obstacle that needs to be overcome before it can be commercially exploited. Currently, there are considerable gaps in research on reaction dynamics, process integration and overall economics [16].

In summary, developing innovative strategies and techniques which effectively reduce straw resistance in order to obtain a highly selective synergistic conversion of the three major components (cellulosic, hemicellulose, lignin) into a highly value-added product is crucial in order to overcome the current shortage of information and to promote the development of bio-based industries. The purpose of this study is to discover these key problems, so as to provide a new scientific basis and technical approach to exploiting high-valuable straw resources.

2. Analysis of the structure-activity relationships in straw raw materials

2.1. Cellular-level microstructural differences

The difference in cell structure of wheat stalk is a major factor that influences its bioconversion efficiency. The major cause of this change lies in the fact that the structure of the cellulose, the hemicellulose and the lignin are different, and the interaction between them is very obvious. Cellulose is a type of linear polysaccharide composed of glucose and beta-glycosylation [1,4], which results in microfibrils and macrofibrils with crystalline or amorphous regions. The structure of this structure makes the fibre very strong, but the highly ordered crystalline region of the fibre is also remarkably resistant to degradation. The hemicellulose is a noncrystal polysaccharide, containing several sugars, such as xylose and arabinose. It has a branched structure that is more easily hydrolysed. Lignin is a type of hydrophobic 3-D cross-chain aromatic polymer, which generally binds to cellulose and hemicellulose via chemistry and hydrogen bond, forming a physical barrier that inhibits hydrolysis and microbial invasion [6,16].

For example, in wheat straw, the binding of lignin to hemicellulose or cellulose enhances the overall degradation capacity [3]. The results of SEM indicate that the grain grain has changed from the intact and smooth appearance to the rough and disordered form with cracks and cracks. This indicates that pretreatments (such as fractional DES or hydro-thermal treatment) may effectively destroy and improve fiber accessibility [4,15]. It was found that the high density of the cell wall of wheat stem was damaged by hydrothermal treatment, and the separation efficiency of lignin was improved [2]. The cooccurrence of crystalline region and noncrystalline region affects the conversion performance of cellulose. For instance, the fibrous structure of corn starch is completely

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destroyed in the aqueous phase of the α-valerolactone and the depolymerisation process is more complete [8].

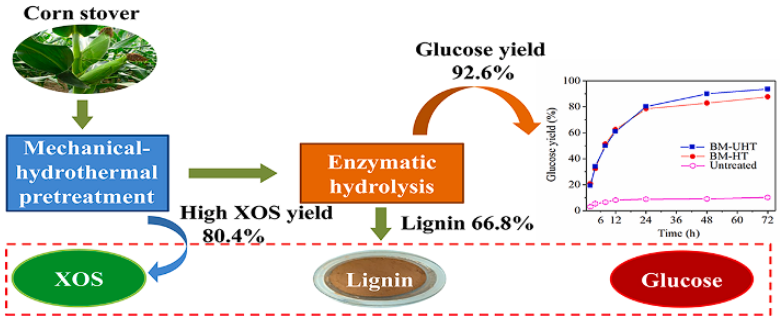

Figure 1. The influence of pretreatments on time yield of maize stover [15]

There are significant differences in the microstructure of both components: hardwood lignin is predominantly composed of the syringyl part, which accounts for 70 to 95%, whereas softwood and grass lignins (such as corn starch) have lower syringyl (< 5%) and higher C-C bonds, leading to significant differences in depolymerisation yield [18]. In general, the cell structure of stem biomass has the characteristics of fibrous microfiber, which is enclosed with semi-cellulose. The three components form a strong whole by covalent and hydrogen bonds. The basic reason for their degradation is the layered structure (in which cellulose accounts for about 40 – 60%, hemicellulose 20 – 40%, and lignin 10 – 25%) [9,11]. Therefore, further research on microstructural changes will be helpful for optimization of pretreatment process and increasing the transformation efficiency of biomass.

2.2. Mechanisms of component interactions

The mechanism of constituents' interaction is very important for the structure and activity relations of straw. They are primarily manifested in the chemical bonding and physical interactions among lignin, cellulose, and hemicellulose. These mechanisms have a direct impact on the mechanical strength, resistance to degradation, and conversion pathways of biomass. Lignin can be combined with cellulose and hemicellulose by covalent links (e.g. phenylglycan, benzenebenone, γ, covalently, and acetoacetate) to enhance the overall stability of the biomass. This results in what is called "biomass resistance", which prevents the entry of the reagent and the development of the response [6].

Thus, for example, when the hemicellulose is joined with lignin, it is easy for chemical bonds (e.g. ester bonds) to break down in hydrothermally pretreatments, resulting in a marked decrease in sugar content [2]. At the same time, the interaction between the hemicellulose and the cellulose by means of hydrogen bonds is very difficult. Selective removal of the hemicellulose may, however, retain the integrity of the fibre and thus obtain a higher sugar yield in the following enzyme hydrolysis [15].

Component interactions also involve dynamic processes within reaction networks. For instance, the C20 precursor can be obtained by means of a sequence of reactions, including Aldol Condensation and Michael Addition, from the stalk, for instance, Levulinic Acid (LA) and Furfural (FFA). This shows a complicated response mechanism between the constituents of biomass [14].

During catalytic conversion, synergistic effects among metal components are key to enhancing performance. For example, in hydrogenolysis processes, alkyl-aryl ether bonds undergo selective cleavage and reduction, resulting in the conversion of lignin into monomers, dimers, and low

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molecular weight oligomers (called "bio-oil") [13]. In addition, Ca2 +, Mg2 + and Na + can promote the formation of small molecules, whereas Ca2 + and Mg2 + increase the selectivity of ketones. The introduction of these ions by sea water can optimize the pyrolysis gas composition [5].

On the other hand, the lignin prevents the cellulose from being in contact with the fiber, which decreases the enzyme hydrolyzation efficiency. Conversely, it may also be involved in non-productive cellulose absorption, which may reduce the activity of the enzyme and the catalyst even more [9]. But in the reduction catalyst separation (RCF), the primary extraction and degradation of lignin occurs, whereas the sugars remain. The method can get up to 94 percent of the lignin removed and 91 percent of the cellulose and 83 percent of the hemicellulose are preserved [12]. Formaldehyde is a stabilizing agent, which not only enhances the extraction of lignin, but also leads to the formation of C-C bond with lignin by alkylation, thus prolonging the carbon chain of the product and raising its carbon content [18].

These interaction mechanisms increase the complexity of straw structure. Nevertheless, by means of specific pre-treatment (e.g. hydrolysis of the ester bond in an alkali state, with a minimal energy barrier of 36,449 kJ/mol), it is possible to optimise the conversion path to improve the use of the biomass [1,11].

2.3. Application of advanced characterization techniques

High level characterization technology is of great importance to clarify the structure and activity relation of straw. The results show that they can be used as a basis for optimizing pretreating and converting strategies. The most common technologies are Fourier Transform Infrared Spectroscopy (FT-IR) or Scanning Electron Microscopy (SEM). By way of example, FT-IR and SEM were used to analyse the structural variation of straw surface following CO2 laser plasma treatment, which proved that it could improve the saccharifying ratio of rice grains efficiently. The SEM analysis also showed that the surface of the original material was usually smooth and compact, while the SR (SR) surface formed by DES separation showed folds and holes. This suggests that the pre-treatment results in substantial changes in the fibre's microstructure [4].

In addition, the combination of several technologies enables a more complete evaluation of the pretreatments. The related research uses SEM, XRD, FTIR, GPC, and laser granularity analysis to assess the variation of pre-treated maize stover chemistry, shape, crystalline structure, and molecular weight [15]. Gas Chromatography-Mass Spectrometry (GC-MS), FT-IR, 2D HSQC NMR (2D HSQC NMR) and Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS) were used for analysis of the reaction mechanism. It is a very accurate method to explain the relation between structure and activity [13]. Two dimensional HSQC NMR or MALDI-TOF MS, for instance, may reveal a particular mechanism for lignin binding cleavage, for instance, in the process of hydrophilicity [13].

Advanced characterization technologies have also been applied to the study of catalysts. The presence of cobalt in Co0.15/N-C catalyst was demonstrated by means of High Angle Ring Dark-Field Scanning Transmission Electron Microscopy (HAADF-STEM), X-ray Photoelectron Spectroscopy (XPS), X-ray Absorption Near Edge Structure (XANES) and Extended X-ray Absorption Fine Structure (EXAFS). This helps in the understanding of the synergistic effects of the catalyst [12]. The "GC" was applied to quantitative determination of Levulinic Acid, and "Van Soest Process" was applied to analyse the constituents of Furfural Residue and Levulinic Acid, showing that the Characterization Techniques were applied in practice [22].

On the one hand, the integrated use of those technologies has shown microstructural changes in the feed material, for example, the transformation from the initial density to the porosity. Moreover,

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it also quantizes the reaction products, so as to supply relevant data for the purification of biomass. Finally, it strongly promotes the high value use of straw resources.

3. Reaction engineering of directed conversion

3.1. Pretreatment coupling strategies

In the area of Directed Transformation Reaction Engineering, a new approach to preprocess coupling is a crucial element to effectively deconstruct the lignocellulose. The core goal of the project has also evolved from simply "component separation" to progressively aiming to "prepare highly active and low resistance reaction precursors for subsequent catalytic conversion." Among the current strategies, they can be broadly classified into three categories according to their respective mechanisms of action:

Physical and chemical coupling cell wall breakage is used to damage the macro-structure of biological material, thus increasing the penetration and efficiency of the chemical agents. For example, ball-milling-hydrothermally coupled pre-treatment could markedly decrease the crystallization rate of cellulose, and raise the yield of oligomeric xylose and glucose from maize straw to 80.40% and 92.60% [15]. Steam explosion uses the instantaneous release of physical force at high temperature and pressure, synergizing with the cleavage of chemical bonds (such as C – O – C bonds) between hydrolyzed hemicellulose and lignin to achieve effective component separation [16].

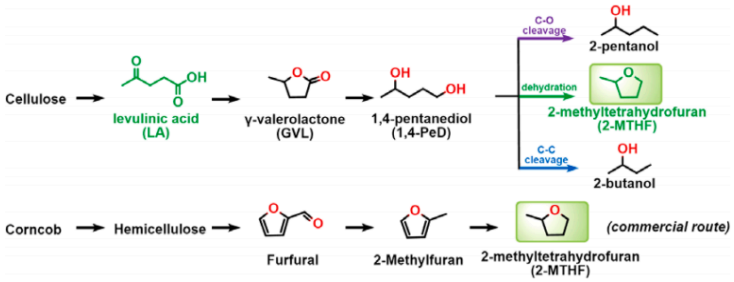

Figure 2. The reaction pathway for the production of 2-methyltetrahydrofuran (2-MTHF) from biomass [16]

The chemistry synergetic precision dismantling path emphasizes the design of a particular chemical environment for the selection of the critical parts. The sequence of acid and alkaline pre-treatment is a typical example. In the acidic process, hemicellulose is eliminated, and then the alkaline process is used to dissolve the lignin, so that the enzyme hydrolyzation ability of the cellulose is increased. As a consequence, the yield of glucose and xylose is 89,5% and 97,0% [6]. By optimizing the conditions (for example, a Cys/LA system), a more advanced deep-eutectic Solvent (DES) fractionates not only efficiently desorbing the lignin but also uses its distinctive -SH group to quench the carbocations, effectively inhibiting the condensation side-reactions in the process of separating lignin [4]. Likewise, in acid catalyzing lignin extraction, the stabilizing strategy depends on the formation of a stable C-C bond in order to avoid the condensation of lignin, which is the basis for high value use of lignin [18].

Middle Engineering and Process Integration Strategy includes the introduction of particular media or coupling reaction steps to optimize reaction paths. For instance, in a two-phase aqueous system (e.g. DUMESIC), an organic phase is cleverly utilized to extract the product in situ when acid catalyzes HMF production. This is effective in decreasing the retention and decomposition of

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the product in the water phase, thus improving the production rate and minimising the adverse effects [7]. Sea water soaking makes full use of various kinds of metallic ions rich in natural sea water, for example, K +, Na +, Ca 2 + and Mg 2 +. This leads to and improves the yield of ketone platform compounds in subsequent pyrolyses, reaching a yield up to 39.13 percent, which certainly opens up a new path for low cost pre-treatment [5].

3.2. Innovations in catalytic systems

Undoubtedly, innovative catalytic systems are the main driving force behind the conversion of biomass into specific pathways. Their developmental course is evolving: starting with the conversion of single elements into co-existing ones, and then from homogeneous to heterogeneous, the catalyzer has switched from expensive precious metals to less expensive non-precious metals. At present, the focus is on the accurate design of the active site and optimal reaction medium, thus achieving highly selective conversion and protecting environment.

In catalyst design, researchers strive to construct synergetic catalytic systems to address the complex and diverse chemical bonds present in biomass. Two functional catalysts, for instance, are able to effectively cascade several reaction steps through integration of different active centers. During dehydration of 5-HMF, a combination of Lewis and Brønsted acid is required. Due to catalytic synergy, either homogeneous (for example, AlCl3 · H2O/HCl) or heterogeneous solid acids (for example, sulphonic acid resins) have high productivity. Bimetal catalysts, for example NiCo/γ-Al2O3, have demonstrated excellent activity and product selectivity in converting levulinic acid into a fuel molecule like 2-MTHF, which is achieved by modulating the electric effect between the metals [17,21]. In the frontier region where Co0.15/N-C is used as a catalyst, the nuclear efficiency is nearly maximum, so that a new model is established for producing phenol.

Innovation in reaction media and stabilisation strategies is also critical. Apart from effective dissolving of the biocomponents [3], it is possible to suppress the condensation side reaction of lignin by quenching the reaction intermediate, e.g. carbocation, with the result that the subsequent conversion can be effective [4], using a green solvent, e.g., an ion or a deep-eutectic solvent (DES). Furthermore, the two phase solvent system (for example γ-valerolactone) can significantly reduce the polymerization and degradation caused by the in-situ extraction of the active platform molecules like HMF and furfural, leading to higher final yield [8].

Despite certain advances, current catalytic systems continue to face significant innovative challenges, such as a trade-off between activity, selectivity and economical viability. Although the activity of Pt and Ru is very high, the high price of these compounds is a significant barrier to large-scale use [23]. Non-precious metal systems, such as Ni and Co, tend to have high activity but often face limitations like insufficient cycle stability and leaching susceptibility [17]. In addition, most catalytic converters are intended for both a model and a single component. To arrive at a more accurate conclusion, it is necessary to systematically assess the capacity of the impurities and their appropriateness for different components of these catalysts, whether they are real or complex.

3.3. Process intensification technologies

Process enhancement techniques are designed to overcome the limitations in efficiency and economy of conventional biomass transformation through the introduction of outside field energy, new solvent systems, and integration techniques. Current related research primarily revolves around three different levels:

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Enhanced Mass Transfer and Reaction Processes through External Field Energy: Making use of the special "nonthermal effect" and volume heating properties of the physical fields (e.g., microwave) [6,9] and ultrasonic [15], it is possible to substantially improve the weight and heat transfer. Additionally, they can disrupt the crystalline regions of biomass and effectively reduce the formation of inhibitors. Microwave pretreatments, for instance, can effectively remove up to 71 percent of the lignin in wheat straw [9]. Nevertheless, the energy use involved in these technologies and the problems of homogeneous distribution of power in deployment are one of the problems that need to be solved in order to apply them in an industrial manner.

Solvent Engineering & Reaction Medium Design: Instead of just being a catalyst, the choice of solvents has become a critical part of the process enhancement. A two-phase solvent system (with reference to the one described in) [7,16] can efficiently inhibit the over-decomposition and side-reaction of the active platform molecules, e.g. HMF, by means of in situ extraction, thus increasing the productivity. In addition, the successful use of organic substances like water (referred to in) [21] and organic solvents (as mentioned in) [19] shows that they have the potential to reduce the environment and reduce costs. Subsequent research, through molecular dynamics simulations (such as those conducted in) [4,17] has further revealed the microscopic interaction mechanisms between solvents and reactant molecules, establishing a theoretical basis for the more rational design of solvent environments.

System Integration and Multiple Technologies Coupling: Integration of upstream pre-treatment, catalyst transformation, and downstream separation is critical to making this process economically viable. For example, the coupling of the membrane [24] with the reaction method may result in the removal and purification of the product in real time. The development of multi - step tandem catalysts [18] allows to convert biomass directly to higher HC in one chain of reaction, thus eliminating the need for intermediate separating and purifying steps and substantially increasing nuclear economics.

4. Application performance evaluation of platform chemicals

4.1. Synthesis of biodegradable materials

Platform chemicals have shown significant potential as substitutes for conventional petroleum based plastics. Recent studies have made it clear that the lignin obtained from the biomass of wheat straw can be effectively transformed into a variety of organic acids, including lactic, acetic, and citric acid by enzymolysis and fermentation. The organic acids may also be utilized for the synthesis of commercially manufactured biodegradable plastics such as PLA (PLA) [6,24]. In addition, it is possible to transform the cellulosic fraction of straw into bio-ethanol, which is used as a precursor to renewables and biodegradable materials [3]. Furthermore, the quality of the cellulose obtained by fractionating may be further treated as a lignocellulosic nano-fibre (LCNF) to produce a membrane with a high intensity as well as a high degree of transparency, thus enhancing the potential of its use in advanced biological materials [4].

As far as the furan-based platform is concerned, the FDCA (FDCA) as the main monomer can be made into the production of biogenic polyester PEF, which can be substituted for the wide range of oil based PET, and is widely applied in the fields of packing and fibre, inter alia, [16]. Phenol monomers (e.g., G1, S1), which are obtained from lignin, may also be utilized for synthesis of polyesters with excellent heat stability and adhesion by reaction like epoxidation and ring opening alternative copolymerizations [12].

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Nanocellulose is one of the most important substrates in PLA, which can greatly enhance the mechanical, heat, and barrier performance of PLA. There is no doubt that this is an appropriate solution for the production of light and high strength biodegradable bio-based plastics [9].

A clearly defined process path has been established for making use of the natural ingredients of straw for production of biodegradable plastics and cellulosic membranes [19]. In addition, BPA could be a substitute for BPA, creating environment and health hazards, and could also be applied to produce high performance polymeric materials like epoxies and polycarbonate, thus extending the range of green materials [10].

4.2. High-value utilization of fine chemicals

High value transformation of platform chemicals plays an important role in increasing the economical efficiency of biomass refining. Their products are widely used in all kinds of fine chemistry industries, including pharmaceuticals, perfumes, fuels, and polymeric monomers. Based on the hydrolyzation of hemicellulose and cellulose, it is possible to produce HMF and furfural by dehydrating reaction. The latter may then be transformed into a multitude of high added value chemicals, for example, FDCA, 2,5-dimethyl furan (DMF), and levulinic acid by means of a variety of catalysts, which comprise oxidative and hydroxides [6,16,20]. Of these, 2-methyl tetrahydrofuran (2-MTHF) is considered as one of the most promising biofuels and petrol additives because of their poor water-miscible, high-calorific and energy-dense properties [17].

The pathways for high-value utilization of lignin are also diverse. By hydrogen peroxide or catalysis decomposition (e.g., CMF @ Co-MoS $_2$), it is possible to selectively produce monoophenolic compounds (e.g., guaiacyl propane and syringyethane) with a yield of up to 43%. The phenol monomers are useful for the synthesis of high strength adhesives or for direct use as a chemical feedstock [4,9,12]. Furthermore, the high selectivity of 4-PROPYL-SUBSTITUTED Syringosa and Guaiacol from lignin (which has a selectivity of 84%) also underlines their high value [12].

As an additional high value-added product, Xylooligosaccharides (XOS) could reach 80.40 percent, and the X2-X4 constituents had pre-biotic properties representing 26.97%, which showed considerable market value [15]. In addition, the small molecular platform (LA) and the furfural (FFA) may be transformed into C12 - C18 by means of the condensation and hydrogenation (HDO) reaction. This increases the CO 2/H ratio to 95.91%, which is why they are suited to the high end fuel markets [14]. High-carbon aromatics (e.g. 1-methyl-3-propylbenzene) may be used as a premium ingredient in jet petroleum [18].

The range of products derived from the platform compounds, such as furfural, levulinic acid, and ketones, is very wide, covering a wide range of applications, including solvents, pharmaceutical intermediates, fragrances, adhesives, dyes, and pesticides [5,10,11,22,23,25]. In addition, the successful synthesis of succinic acid [24] and HMF derivatives such as BHMTHF and N-BDB [19] is fully supported by the feasibility of biomass pathways for the production of fine chemicals [2,8,13,26].

4.3. Closed-loop agricultural application

The concept of platform chemicals has created a highly efficient closed loop application model in agriculture. It aims to turn agricultural waste, like straw, into energy, fertilizer, and animal feed, so that it can circulate and increase its value. Straw biogas technology is a typical application example, and it has been widely used in China. In some European countries, for example, Germany and

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Sweden, the biogas is further purified into vehicle grade biomethane, which has successfully transformed agricultural waste from a "source of pollution" to "clean energy" [3].

In terms of nutrient circulation, the straw can be transformed into organic fertilizer by anaerobic fermentation or composting, and then applied to the farmland to supplement the organic matter. At the same time, biomass generated by pyrolysis not only helps to improve the quality of soil and increase fertility, but can also be used for waste water treatment, thus achieving the double effect of cleaning the environment [19]. Microbial treatment also plays a significant role in the agricultural closed loop. For example, the treatment of maize husks by white rot fungi may increase their nutritional value as animal feed, thus making use of agricultural waste in animal husbandry [9].

Additionally, the chemicals themselves can be used to derive novel agricultural inputs. For instance, the organic potassium fertilizer produced from levulinic acid has shown remarkable efficiency in fertilizer use, as well as the biological control functions of cold-resistant, drought-resistant and pest resistant. At the same time, it is environmentally sound, non-toxic and free of residues, which is clearly a future trend for organic farming [10]. All these kinds of application modes have built up the cycle economy system from farm to farm, which has greatly improved the sustainability of agriculture system.

5. Conclusions and prospects

Although it has a promising future, there are many complicated technological and economical challenges in converting wood pulp into industrial production. Technically speaking, those challenges extend across the whole process chain.

During the pre-treatment phase, the conventional process, for example, strongly acidic or alkaline, may lead to a number of secondary problems, which may be caused by device corrosion, environment contamination, and inhibition. At the same time, certain green solvents, e.g. ion fluids and DES, are confronted with cost and recycling problems. For the catalyst transformation phase, this is the place with the greatest concentration of bottlenecks. In terms of the performance of the catalyst, there is a major drawback: the expensive price of the precious metals is relatively high, whereas the nonprecious metal catalysts such as Ni and Cr usually have a low cycle stability and are susceptible to sintering or leaching [17]. Furthermore, the control of the route is far from ideal: an effective depolymerisation mechanism for the relatively stable C-C bonds in lignin is not yet fully understood. Because of the complexity of the reaction net for HMF and furfural, it is easy to induce a polymerisation or condensation, which results in the inactivation of the catalyst and a reduction in the selectivity of the target product [13,14].

In terms of the process integrating and separating phase, it requires a lot of energy to separate and purify the downstream products. In addition, the co-products produced in the course of the reaction not only lead to carbon loss, but also to add to the load of separation. Economically speaking, pretreatments usually make up a large part of the overall process cost. Furthermore, the operating costs are influenced by the life of the catalyst and the efficiency of the product. Nevertheless, substantial cost optimisation opportunities have been shown by enhancing the process and by making full use of the waste, e.g. by turning the residual into active carbon, and by the development of low cost catalytic converters such as the use of red sludge [5].

Taking into account all these factors, it is necessary for further studies to overcome the limits of simple optimization of individual technological parameters and concentrate on the development of systematic solutions: the development of low-cost and stable catalysts, the elucidation of the micro-mechanics of critical reactions for accurate control, and the final closing of the "viable" status to "economically viable" status by integrating and optimizing the whole process.

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