Review Article

Chemocatalytic Conversion of Cellulose into Key Platform Chemicals

Guangbi Li,1,2,3,4 Wei Liu,1 Chenliang Ye,5 Xiaoyun Li,1 and Chuan-Ling Si1,2,3,4

1Tianjin University of Science and Technology, Tianjin 300457, China
2Jiangsu Provincial Key Laboratory of Pulp and Paper Science and Technology, Nanjing Forestry University, Nanjing 210037, China
3State Key Laboratory of Tree Genetics and Breeding, Northeast Forestry University, Harbin 150040, China
4State Key Laboratory of Pulp and Paper Engineering, South China University of Technology, Guangzhou 510640, China
5Davidson School of Chemical Engineering, Purdue University, 480 Stadium Mall Drive, West Lafayette, IN 47907, USA

Correspondence should be addressed to Chuan-Ling Si; sichli@tust.edu.cn

Received 2 May 2018; Accepted 4 July 2018; Published 14 August 2018

Academic Editor: Yun-yan Wang

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Chemocatalytic transformation of lignocellulosic biomass to value-added chemicals has attracted global interest in order to build up sustainable societies. Cellulose, the first most abundant constituent of lignocellulosic biomass, has received extensive attention for its comprehensive utilization of resource, such as its catalytic conversion into high value-added chemicals and fuels (e.g., HMF, DMF, and isosorbide). However, the low reactivity of cellulose has prevented its use in chemical industry due to stable chemical structure and poor solubility in common solvents over the cellulose. Recently, homogeneous or heterogeneous catalysis for the conversion of cellulose has been expected to overcome this issue, because various types of pretreatment and homogeneous or heterogeneous catalysts can be designed and applied in a wide range of reaction conditions. In this review, we show the present situation and perspective of homogeneous or heterogeneous catalysis for the direct conversion of cellulose into useful platform chemicals.

1. Introduction

With the increasing global demand for renewable and valuable chemicals and fuels, social reliance on biomass materials and sustainable technologies is imminent [1–3]. These technologies are booming and will be able to effectively use renewable resources to decrease their dependence on nonrenewable resources in order to promote social progress and development [4–7]. Currently, a promising strategy for alleviating the depletion of energy is to convert lignocellulosic biomass into high-value chemicals and fuels, which has become the current research hotspots [8–34]. As an environmentally friendly, renewable, sustainable, inexpensive, and nonfood biomass resource, lignocelluloses have gained widespread interest for the production of valuable fuels and chemicals with a variety of designed processing technologies [8, 9, 35–44]. Lignocelluloses are very abundant in the world; it is estimated that the annual global production is about $1.1 \times 10^{11}$ metric tons [45]. Thus, researchers have explored the use of lignocellulose as relatively low-cost carbon resource to produce key platform chemicals and fuels. It is well known that lignocellulose as an important biomass resource consists mainly of cellulose, hemicellulose, and lignin [46]. Cellulose accounts for the largest proportion (30–55 wt%) of lignocellulose compared to lignin (25–30 wt%) and hemicellulose (25–30 wt%) [47–57], and it is a linear polymer consisted of numerous glucose units covalently linked by β-1,4-glycosidic bonds and closely bound by intramolecular and intermolecular hydrogen-bond networks (Scheme 1) [58–66]. Most cellulose is locked in the form of lignocellulose in nature; hemicellulose and lignin need be removed by extensive cleaning and purification processes. For example, Sasaki et al. reported that semibatch hydrothermal treatment could remove hemicellulose and lignin and recover cellulose from sugarcane bagasse biomass without any catalyst or organic solvent [67]. An average of about 700,000 billion metric tons of cellulose is synthesized annually through photosynthesis of plants using solar energy in the
world, but only 0.1 billion metric tons of cellulose is being used as feedstock in paper, food, pharmaceuticals, and textiles [68–73]. Therefore, a large amount of underutilized cellulose is wasted every year, and new technologies need to be developed to make better use of cellulose resources. In order to reduce excessive dependence on fossil fuels, it is very important to convert cellulosic biomass into renewable and valuable chemicals and fuels. As the most abundant biorenewable materials on earth, the conversion of cellulose to renewable chemicals and fuels to satisfy the growing global energy demand will attract widespread attention of academia and industrial fields [18, 74–97]. However, apart from papermaking and materials industry, a low reactivity of cellulose has seriously hindered its application in the chemical industry. Recently, researchers have designed and screened various heterogeneous or homogeneous catalysts under a variety of reaction conditions; heterogeneous or homogeneous catalysis for the transformation of cellulose into key platform molecules is expected to overcome this problem [98–102].

In this review, we focus on the recent advances in homogeneous or heterogeneous catalysis for direct conversion of cellulose into key platform chemicals, particularly glucose, polyols, and furans, except for the production of biofuels. The thermochemical such as pyrolysis and gasification, or enzymatic process, is beyond the scope of this review. We review the recent process of direct chemocatalytic conversion of cellulose to key platform chemicals (Scheme 2), which is helpful for researchers to build a deeper understanding of existing chemical processes on the value-added utilization of cellulose and rationally design a more efficient chemical catalytic conversion system for cellulose.

### 2. Pretreatment Technologies for Decreasing Rigid Structure of Cellulose

Due to tight van der Waals interactions and intramolecular and intermolecular hydrogen-bonding networks, cellulose is chemically stable, structurally rigid, and insoluble in water or common organic solvents [103–111]. The recalcitrance of cellulose is a bottleneck that affects its sustainability and cost-effective utilization for the conversion of cellulosic biomass into key platform chemicals. Thus, efficient pretreatment of cellulose plays an important role in the

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Scheme 1: Chemical structure of cellobiose with $\beta$-1,4-glycosidic bonds and intra- and intermolecular hydrogen bonding.

Scheme 2: Direct catalytic conversion of cellulose into key platform chemicals.
conversion of cellulose into value-added chemicals. In recent years, various pretreatment strategies were explored for cellu-
lose [72, 112–115]. Among these pretreatment techniques for
dissolving the robust structure of cellulose, milling methods as
typical mechanical techniques have been widely used, such as
ball-milling [116–118]. This can disrupt the crystal structure
of native cellulose by cleaving hydrogen bonds in cellulose
during processing and reduce the degree of polymerization
decrease the particle size and crystallinity of cellulose,
thereby increasing the glucose yield [53, 119–136]. Kobayashi
et al. found that the glucose yield was 88% obtained by mixed
ball-milling (60 rpm for 2 days) of catalyst (K26, the purified
carbon) and microcrystalline cellulose (MCC), which was
much higher than that obtained by single ball-milling
(30.0%, 60 rpm for 2 days), indicating that mixed ball-
milling was more efficient than single ball-milling for the
pretreatment of MCC under the same conditions (180°C
and 20 min) (Table 1, entry 1) [136]. This is due to the fact that
mixed ball-milling improves the contact between MCC and
catalyst and also promotes the collision of catalyst and MCC
at the solid-solid interface. Suzuki et al. reported that
jet-milling treatment only reduced particle size without
decreasing the crystallinity index, whereas ball-milling and
rob-milling processes converted the crystalline of cellulose
into amorphous within one hour [127, 137]. Kafy et al. dem-
onstrated that aqueous counter collision (ACC) equipment
mechanically isolated the cellulose nano-
fibers into amorphous cellulose
fibers (CNFs) using 200.0 MPa water jets col-
colliding each other and decreased the lengths of cellulose nano-
fiber (CNF) within 15–22 nm and the length of CNF within
700–1000 nm (Table 1, entry 2) [138]. Rol and coworkers
studied twin screw extrusion (TSE) and reported that this
method diminished the width of cellulose nanofibers (CNFs)
within 20–30 nm and increased energy efficiency and solid
content, and the crystallinity and degree of polymerization
(DP) of cellulose fibers were degraded using this mechanical
treatment technology (Table 1, entry 3) [139].

In addition, chemical methods are also used to pretreat
cellulose and its derivatives. Deng et al. reported that after
commercial cellulose was treated by different concentrations
of phosphoric acid (H3PO4), its crystallinity decreased from
85% to 79–35%, and the DP of cellulose reduced from 221
to 209–106, and the decreases in DP and crystallinity of cel-
lulose raised the conversion of treated cellulose to sorbitol
NDM, (65 wt% and higher) as a catalyst without pretreat-
ment (Table 1, entry 2) [138]. Rol and coworkers
studied twin screw extrusion (TSE) and reported that this
method diminished the width of cellulose nanofibers (CNFs)
within 20–30 nm and increased energy efficiency and solid
content, and the crystallinity and degree of polymerization
(DP) of cellulose fibers were degraded by this mechanical
treatment technology (Table 1, entry 3) [139].

Table 1: Pretreatment technologies for the cellulose species.

| Entry | Substrate | Pretreatment | Method | Ref. |
|-------|-----------|--------------|--------|------|
| 1     | MCC       | Mixed ball-milling | Mechanical | [136] |
| 2     | CNFs      | ACC          | Mechanical | [138] |
| 3     | CNFs      | TSE          | Mechanical | [139] |
| 4     | Cellulose | H3PO4        | Chemical | [140] |
| 5     | Cellulose | [C4mim]Cl    | Chemical | [159] |
| 6     | Cellulose | [EMIM]Cl     | Chemical | [51] |

effects on the crystallinity and DP of cellulose. Cellulose is
difficult to be dissolved at relatively high temperatures [141, 142]. In order to improve
the utilization of cellulose, it is particularly important to explore
solvents of cellulose to deal with it as a soluble substrate,
which could increase the reactivity of cellulose and enhance
the conversion of cellulose into high-value chemicals [143]. Burchard et al. demonstrated that a complex was formed
between Schweizer’s reagent and cellulose, and the reagent
resembled the hydrogen bonding of cellulose and dissolved
sorbitol [144]. The researchers reported that the mixtures
of N,N-dimethylacetamide (DMAc) and lithium chloride
(LiCl) could dissolve cellulose owing to cleaving hydrogen
bonds of cellulose with the chloride ion [145–147]. Recently,
ionic liquids (ILs) as cellulose-dissolved green solvents have
attracted extensive attention [72, 148–153]; this is because
ILs have many excellent properties as compared to other tra-
ditional solvents, such as controllable adjustment of physico-
chemical properties, low vapor pressure, wide liquid range,
high chemical and thermal stability, high solvation ability,
and wide electrochemical window [154–156]. Swatloski and
coworkers demonstrated that ILs 1-butyl-3-methylimidazo-
lum chloride ([BMIM]Cl) could dissolve cellulose without
derivatization [157]. The dissolution mechanism of cellulose
in ILs is largely believed to be formation of hydrogen bonds
between hydroxyl groups of cellulose and anions of ILs
[158]. Li and Zhao demonstrated that the glucose yield
reached 43% at 100°C for 540 min in the homogeneous
hydrolysis of cellulose using IL 1-butyl-3-methylimidaz-
lum chloride ([C4mim]Cl) as a solvent to completely dis-
solve the cellulose and dilute sulfuric acid (H2SO4, mass
ratio of acid/cellulose = 0.11) as a catalyst without pretreat-
ment (Table 1, entry 5) [159]. The glucose yield was higher
than just water as a solvent (dilute H2SO4 as a catalyst, mass
ratio of acid/cellulose = 0.92) or concentrated sulfuric acid
(65 wt% and higher) as a catalyst. Binder and Raines
observed that the yield of cellulose hydrolysis to glucose
was increased to nearly 90% in 120–240 min by adding water
gradually to IL-HCl solution [ILs 1-ethyl-3-methylimidazo-
lum chloride ([EMIM]Cl) as a solvent and HCl (20 wt%, mass
ratio of HCl/cellulose)] as a catalyst] (Table 1, entry 6)
[51]. Li and coworkers showed that ILs with unsaturated
cyclic cations generally dissolved cellulose better
[160]. Li et al. reviewed in detail various structures and prop-
erties of ILs that dissolved cellulose in recent years [161].
With the rapid development of science and technology, it is
believed that more efficient pretreatment technologies will
be applied for the pretreatment and conversion of cellulose.

3. Direct Catalytic Conversion of Cellulose into
Key Platform Molecules

3.1. Glucose. It is well known that efficient hydrolysis of
cellulose as a renewable bulk and nonfood carbon source
to glucose is an important challenge for the use of real-
ization of biorefinery, which is the starting point of the
overall catalytic conversion chain (Scheme 2) [162–168].
Glucose is a versatile platform chemical to value-added prod-
ucts such as 5-hydroxymethylfurfural (5-HMF), bioethanol,
and biodegradable plastics [102]. Early, researchers used mineral acids such as phosphoric acid (H₃PO₄), sulfuric acid (H₂SO₄), hydrochloric acid (HCl), perchloric acid (HClO₄), hydrofluoric acid (HF), and nitric acid (HNO₃) as representative homogeneous catalysts for the hydrolysis of cellulose into glucose [162, 169–173]. These mineral acids are cheap and widely used in the early hydrolysis of cellulose to glucose. However, they have some insurmountable bottlenecks owing to their difficulties in poor recyclability, wastewater treatment, reactor corrosion, and other issues [98, 174–176]. Therefore, there is an urgent need to develop a green and sustainable hydrolysis process of cellulose into glucose. As is well known, not only are ILs not only excellent solvents for dissolving cellulose [177–191] but also ILs modified by acidic groups can effectively catalyze the hydrolysis of cellulose into glucose in homogeneous and heterogeneous systems [192–214]. Jiang et al. demonstrated that the acidic IL 1-butyl sulfonic acid-3-methylimidazolium chloride ([C₄SO₃Hmim]Cl) exhibited excellent activity in the hydrolysis of cellulose into glucose compared with other three acidic IL catalysts including [Bmim]Cl, [C₄SO₃Hmim]HSO₄, and [Bmim]HSO₄ at 100°C for 1 h (Table 2, entry 1) [215]. This is owing to the stronger acidity strength of the [C₄SO₃Hmim]Cl catalyst. Parveen et al. reported that the glucose yield reached 47.9% using 40% Brønsted acidic ionic liquid 1-(4-sulfobutyl)-3-vinyl-1H-imidazol-3-ium hydrogensulfate (IL) immobilized on polymer support via copolymerization with 4-chloromethyl vinyl benzene (CMVB, 40% IL/CMVB, Scheme 3) as catalyst and water as solvent, which was higher than that of 0 or 100% IL/CMVB catalyst.

**Table 2: Overview of glucose yields from the hydrolysis of cellulose in the typical catalytic system.**

| Entry | Substrate | Solvent       | Catalyst | Pretreatment | T/°C | t/min | Yield/% | Ref.   |
|-------|-----------|---------------|----------|--------------|------|-------|---------|--------|
| 1     | Cellulose | [Bmim]Cl + DMF| [C₄SO₃Hmim]Cl | Stirring     | 100  | 60    | 95.0    | [215]  |
| 2     | MCC       | H₂O           | 40 wt% IL/CMVB | Stirring     | 160  | 360   | 47.9    | [216]  |
| 3     | MCC       | 0.015 wt% HCl-H₂O | CD-C | Ball-milling | 200  | 90    | 74.0    | [220]  |
| 4     | Cellulose | H₂O           | Polymera  | Ball-milling | 120  | 1440  | 94.9    | [229]  |
| 5     | MCC       | H₂O           | 10-SGOC   | /            | 160  | 300   | 17.76   | [230]  |
| 6     | MCC       | H₂O           | 1 M CB    | Ball-milling | 150  | 1440  | 34.6    | [233]  |
| 7     | MCC       | H₂O           | GO        | /            | 179.85 | 60  | 61 ± 4  | [234]  |
| 8     | MCC       | [Emim]Cl      | HY/silicalite-1 | Stirring   | 110  | 480   | 50.8    | [235]  |

*aBifunctional porous polymer bearing boronic and sulfonic acids as cellulase-mimetic catalyst; †without pretreatment.

![Scheme 3: Schematic diagram of Brønsted acidic ionic liquid catalyst immobilized on 4-chloromethyl vinyl benzene (CMVB) via copolymerization. Adapted from [216].](image-url)
Su et al. reported that the pretreatment of cellulose and cow dung-based carbonaceous catalyst (CD-C) via mixed ball-milling promoted a synergistic effect for the hydrolysis of cellulose into glucose. The chlorine groups (–Cl) in CMVB promoted the dissolution of cellulose by breaking intermolecular and intramolecular hydrogen bonding, while the sulfonic acid groups (–SO3H) in IL promoted the dissociation of β-1,4-glycosidic bonds to generate glucose units.

Recently, solid catalysts, such as carbonaceous acids, metal oxides, supported metals, H-form zeolites, acid resins, heteropoly acids, magnetic acids, and functionalized silicas, have attracted much attention as promising and appealing catalysts for the hydrolysis of cellulose into glucose due to their excellent properties, such as easy separation, recoverability and reusability from product solutions, and adjustable functional structure of catalysts. Su et al. reported that the pretreatment of cellulose and cow dung-based carbonaceous catalyst (CD-C) via mixed ball-milling effectively enhanced the yield of glucose with 59.3% compared with unmilled catalysts (3.6% glucose yield). Moreover, the addition of trace hydrochloric acid (0.015 wt% HCl) could significantly increase the glucose yield to 74% under the same reaction conditions. The excellent performance of the hydrolysis of cellulose to glucose was attributed to the synergistic effect of the mixed ball-milling pretreatment and the addition of dilute HCl (Table 2, entry 3) [220]. Yang and Pan demonstrated an important improvement in hydrolysis of cellulose to glucose, in which a bifunctional mesoporous polymeric catalyst bearing boronic acid as cellulose-binding groups and sulfonic acid as cellulose-hydrolytic groups was prepared, resulting in an excellent hydrolysis performance (Table 2, entry 4, Scheme 4) [229]. The increase in hydrolysis performance was mainly due to the synergistic effects of more cellulose-attracting groups (boronic acid) and cellulose-hydrolyzing groups (sulfonic acid) and larger surface area of the prepared polymeric solid acids. Zhang et al. reported an effective carbonaceous solid acid catalyst (10-SGOC) for the hydrolysis of cellulose to glucose, which was prepared by hydrothermal carbonization of cellulose using graphene oxide as a structure-directing agent and subsequent concentrated H2SO4 as a sulfonating agent [230]. The yield and selectivity of glucose reached 17.76% and 94.22% at 160°C for 5 h over 10-SGOC catalyst, respectively (Table 2, entry 5). 10-SGOC exhibited excellent glucose yield and selectivity in the case of low mass ratio of catalyst/cellulose compared with previously reported sulfonated solid acid catalysts [130, 217, 231, 232]. This indicated that the combination of functional groups such as –OH, –COOH, and –SO3H and layered structure with good hydrophilicity promoted a synergistic effect for the 10-SGOC catalyst, thereby better facilitating the contact of the catalyst with cellulose and effectively diffusing glucose into water. Li et al. reported a novel sulfonated carbon catalyst (1 M CB) prepared by a fast sulfonating process via a plasma technology in dilute H2SO4 for the hydrolysis of cellulose into glucose (Table 2, entry 6) [233]. The results demonstrated that a high yield of glucose with 34.6% and good conversion of cellulose with 40.1% were obtained at 150°C for 24 h, and the high yield and conversion were attributed to the higher –SO3H and total acidic densities of the sulfonated carbon catalyst. The combination of microwave irradiation (MW, 200 W, and 179.85°C) as a heating tool and graphene oxide (GO) as a solid catalyst were investigated by Mission et al. for the hydrolysis of MCC into glucose; the results showed that a higher yield of glucose with 61 ± 4% in 60 min was achieved compared with other solid catalysts such as phosphotungstic acid, Amberlyst 15, functionalized GO, and sulfated zirconia (Table 2, entry 7) [234]. This indicated that the combination of GO and MW promoted a synergistic effect for the hydrolysis of MCC into glucose to significantly enhance the catalytic performance, owing to the large surface area and sufficient acid density of the GO catalyst, variety of functionalities of the GO surface, and MW interaction. Yu et al. reported that silicalite-1-modified HY zeolite (HY/silicalite-1) as a catalyst could effectively enhance the selectivity of glucose, significantly reduce the
hydrolysis temperature, and greatly increase the yield of glucose to 50.8% within 8 h in the ionic liquid [Emim]Cl under the same reaction conditions as compared to the non-modified HY catalyst (Table 2, entry 8) [235]. This might be due to a decrease in Lewis acidity of the modified HY catalyst and a decrease in contact probability of Lewis acid sites with sugar caused by the outer silicalite-1 layer.

3.2. Polyols. The conversion of resource-abundant, renewable, and nonedible cellulosic biomass to high-value chemicals is beneficial to the development of a sustainable society. In particular, the direct catalytic conversion of cellulose to polyols is an important part of biorefinery, which has attracted extensive interest to meet the world’s energy needs [236–242]. In this section, we focus on the recent developments in the chemical catalytic conversion of cellulosic biomass into ethylene glycol (EG) and sorbitol, which are widely used in the food industry, pharmaceutical production, cosmetics, and so on.

3.2.1. Ethylene Glycol (EG). With the increase of the market demand of renewable products from biomass, it is highly desirable to design a series of effective catalysts which can control the selectivity of polyols [169, 243–263]. The direct conversion of cellulose to value-added polyols in biorefinery is an attractive and promising approach. Although significant advances have been made in the transformation of cellulose to polyols, the production of quite valuable EG is still challenging [88, 264–272].

Hamdy et al. reported a novel 3Al-15W-3Ni catalyst prepared by one-pot hydrothermal sol-gel process for selective hydrolysis of cellulose into EG. The catalyst showed the multiple active sites and exhibited a high cellulose conversion (100%) and an excellent yield of EG with 76.0% at 229.85°C for 90 min under 4.0 MPa of H₂ pressure (Table 3, entry 1) [273]. Ribeiro and coworkers synthesized a carbon nanotube-(CNT-) supported bimetallic Ni₀.₃-W₀.₃/CNF catalyst prepared via a sequential incipient wetness impregnation method (first loaded with W and then with Ru component) for the hydrolytic hydrogenation of cellulose to EG, leading to 100% cellulose conversion and about 40% EG yield in aqueous solution at 205°C for 3 h of reaction under 5.0 MPa of H₂ pressure, which was demonstrated to be an improved catalytic performance compared with monometallic Ru/CNT or W/CNT catalyst under the same reaction conditions (Table 3, entry 2) [274]. This was because the combination of W and Ru components promoted a synergistic effect for the bimetallic catalyst, thereby increasing the yield of EG. A novel SiO₂-OH nanosphere-supported 15%Ni-20%W/SiO₂-EG catalyst was prepared by Xiao et al. via the incipient wetness impregnation method [275]. When this catalyst was employed for the selective hydrogenolysis of cellulose into EG in aqueous solution, 63.3% yield of EG was obtained at 240°C for 2 h under 5.0 MPa of H₂ pressure (Table 3, entry 3). A good EG yield of the bimetallic catalyst for the conversion of cellulose to EG was attributed to the synergistic effect between W and Ni active sites. Yang et al. prepared a carbon nanofiber-(CNF-) supported bimetallic Ni₀.₃-W₀.₃/CNF catalyst, resulting in 95.0% conversion of cellulose and 33.6% EG yield in aqueous solution at 245°C for 2 h under 6.0 MPa of H₂ pressure. The improved performance of the bimetallic catalyst was attributed to excellent accessibility and uniform dispersion of metal species (Table 3, entry 4) [276]. Li et al. found that the WO₃-supported 1% Ru/WO₃ catalyst prepared by homogeneous deposition-precipitation (HDP) technique was effective for the selective hydrogenolysis of cellulose to EG, leading to 76.0% EG yield with 100% cellulose conversion in aqueous solution at 240°C for 2 h under 4.0 MPa of H₂ pressure (Table 3, entry 5) [277]. The addition of Ru species significantly increased the active site of W⁵⁺, thereby promoting the retro-aldol condensation reaction of glucose and enhancing the etching of H⁺ in aqueous solution for the hydrogenolysis of cellulose to EG, thus obtaining a high yield of EG from cellulose.

3.2.2. Sorbitol. With the gradual depletion of nonrenewable resources, such as fossil fuels and coal, cellulosic biomass, as a large-scale renewable and sustainable carbon source on earth, has attracted wide attention for its catalytic conversion to value-added chemicals, such as the hydrolytic hydrogenation of cellulose to produce sorbitol [140, 278–287].

Zhang et al. prepared a magnetic catalyst (Ni₄.₆₅Cu₄Al₁.₈₁Fe₀.₇₉) for the direct transformation of cellulose to sorbitol, resulting in 68.07% sorbitol yield in 0.06% H₃PO₄-H₂O solution at 214.85°C and 4.0 MPa H₂ after 3 h, which was shown to be an enhanced catalytic performance in comparison to Cu₄Al₁.₇₁Fe₀.₇₂ with about 29% sorbitol yield under the same conditions (Table 4, entry 1) [288]. This indicated that the modification of Ni species improved the catalytic reaction activity, and a synergistic effect might be promoted between active Ni/Cu and Cu sites. Xi and coworkers reported a novel mesoporous nio-

| Entry | Substrate | Solvent | Catalyst | Pretreatment | T/°C | t/min | Yield/% | Ref. |
|-------|-----------|---------|----------|-------------|------|-------|---------|-----|
| 1     | Cellulose | H₂O     | 3Al-15W-3Ni | Stirring    | 229.85 | 90   | 76.0    | [273] |
| 2     | MCC       | H₂O     | 0.8%Ru-30%W/CNT | Ball-milling | 205  | 180  | 40.0    | [274] |
| 3     | MCC       | H₂O     | 15%Ni-20%W/SiO₂-EEG | Stirring    | 240  | 120  | 63.3    | [275] |
| 4     | Cellulose | H₂O     | Ni₀.₃-W₀.₃/CNF | Stirring    | 245  | 120  | 33.6    | [276] |
| 5     | Cellulose | H₂O     | 1%Ru/WO₃ | Stirring    | 240  | 120  | 76.3    | [277] |
up to 69.1% at 160 °C and 5.0 MPa H₂ when 0.4%Ru/AC was ball-milled together with cellulose to sorbitol and observed that the sorbitol yield reached 68.0% in H₂O after 1 h of reaction at 205 °C and 5.0 MPa H₂, which was 10% higher than 5%Ru/NbOPO₄·pH₂ with 57.3% without ball-milled pretreatment (Table 4, entry 2). Zhu et al. synthesized a sulfonic acid-functionalized silica-supported Ru catalyst (3.0%Ru/SiO₂-SO₃H) for the hydrolytic hydrogenation of cellulose to sorbitol, leading to 61.2% sorbitol yield in aqueous solution after 10 h at 150 °C and 4.0 MPa H₂, which was demonstrated to be a better yield of sorbitol than that of the mechanical mixture of Ru/SiO₂ and SiO₂-SO₃H with 43.3% sorbitol yield under the same reaction conditions (Table 4, entry 3) [290]. This indicated that the combination of Ru metal and acidic sites promoted a strong synergistic effect between the proximate Ru site and acid site for enhanced sorbitol yield of 3.0% Ru/SiO₂-SO₃H catalyst in the conversion of cellulose into sorbitol. Ribeiro and coworkers studied an activated carbon- (AC-) supported Ru catalyst (0.4%Ru/AC) for the one-pot transformation of cellulose to sorbitol and observed that the sorbitol yield reached 68.0% in H₂O after 1 h of reaction at 205 °C and 5.0 MPa H₂ when 0.4%Ru/AC was ball-milled together with cellulose, whereas it was only 49.0% when the catalyst and cellulose were separately ball-milled under the same reaction conditions (Table 4, entry 4) [291]. This demonstrated that mix-milling pretreatment enhanced the reaction rates in the hydrolytic hydrogenation of cellulose to sorbitol, which was not owing to the mechanocatalytic hydrolysis in the process of treatment but was mixing. Afterward, Ribeiro et al. prepared an AC-supported Ru-Ni bimetallic catalyst (0.4%Ru-3%Ni/AC) for hydrolytic hydrogenation of cellulose to sorbitol [292]. The addition of Ni species promoted a synergic effect between Ni species and Ru species for the bimetallic Ru-Ni/AC catalyst in the one-pot conversion of cellulose to sorbitol. A sorbitol yield of 70.0% was obtained over the 0.4%Ru-3%Ni/AC catalyst in H₂O after 1 h at 205 °C and 5.0 MPa H₂ when the catalyst was ball-milled with cellulose (Table 4, entry 5).

3.3. 5-Hydroxymethylfurfural (5-HMF). 5-HMF is a promising and versatile biomass-based platform molecule from biorefinery carbohydrates, which can be used to produce various chemicals and liquid fuels currently derived from nonrenewable fossil resources [293–296]. It is worth noting that the production of 5-HMF from renewable cellulose has become an integral part of biorefinery and attracted extensive attention in recent years [297–332].

Li et al. prepared a sulfonated poly(phenylene sulfide) (SPPS) catalyst with strong Brønsted acid sites and a sulfonation degree of 21.8 mol%; when it was used for the direct conversion of cellulose to 5-HMF in IL 1-methyl-3-ethyl imidazolium bromide ([EMIM][Br]) solvent, the yield of 5-HMF with 68.2% was obtained at 180 °C for 4 h (Table 5, entry 1) [333]. DFT calculations indicated that the −SO₃H groups in SPPS play an important role in catalytic conversion, and it acts as a proton donor for Brønsted acids and acts as a proton acceptor as a conjugate base. In addition, the anions and cations of ILs together with SPPS-SO₃H are conducive to stabilizing the transition states and reaction intermediates, which also leads to the easy conversion of cellulose to 5-HMF.

Zhang et al. reported a temperature-responsive heteropolaric (ChH₃PW₁₂O₴₀) catalyst, prepared by H₃PW₁₂O₴₀ and choline chloride (ChCl) as raw materials, which was used for one-pot transformation of cellulose to 5-HMF in the biphase solvent system including H₂O and methyl isobutyl keton (MIBK) (H₂O/MIBK), leading to 75.0% 5-HMF yield and 87.0% cellulose conversion at the volumetric ratio of H₂O/MIBK = 1 : 10 at 140 °C for 8 h (Table 5, entry 2) [334]. Compared to homogeneous H₃PW₁₂O₄₀, the remarkable 5-HMF yield might be attributed to the thermoregulation property and higher Brønsted acidity.

Bai et al. reported a novel bifunctional catalytic system, when the CrCl₃/[R₄N]ReO₄ catalyst was used for the degradation of cellulose into 5-HMF in [Emim]Cl; 5-HMF with a
yield of 49.3% was obtained at 150°C for 30 min under the conditions of 7 mol% of CrCl₃ and 5 mol% of tetramethylammonium perrenenate. The effective catalytic activity of CrCl₃/[R₄N]ReO₄ for the production of 5-HMF from cellulose was attributed to the bifunctional catalytic system of the catalyst, which was better than the single CrCl₃ catalyst (Table 5, entry 3) [335].

Li et al. reported an efficient niobia/carbon catalyst (Nb/C-50, 50 wt% of Nb₂O₅) prepared from niobium tartrate (Nb₂O₅) and glucose as raw materials via carbonization, for the conversion of cellulose into 5-HMF, leading to 53.3% HMF yield and 77.8% total carbon yield in the THF/H₂O biphasic system at 170°C for 8 h (Table 5, entry 4) [336]. What is noteworthy is that the Nb/C-50 catalyst was agglomerated particles and contained suitable Bronsted/Lewis acid sites and weak to medium acid strength, which favored the conversion of cellulose to 5-HMF.

Zhao et al. reported an interesting bifunctional catalytic system using AlCl₃ as the Lewis acidic catalyst and H₃PO₄ as Bronsted acidic catalyst, and when the AlCl₃-H₃PO₄ catalyst was employed for the transformation of cellulose to 5-HMF, the highest yield of 5-HMF with 49.42% was achieved in a single-phase reaction system of 1,2-dimethoxyethane (DMOE) and water at 180°C for 120 min (Table 5, entry 5) [337].

3.4. Levulinic Acid (LA). LA is an important platform molecule, which can be prepared by many acid-catalyzed reactions of renewable biomass resources, which is a versatile raw material for resins, pharmaceuticals, pesticides, dyes, and chemical intermediates [338]. The preparation of LA from biorenewable cellulose has attracted more and more attention of researchers [47, 340–347].

Shen and coworkers reported that a high catalytic activity for the conversion of cellulose to LA with a yield of 39.4% was achieved in the presence of IL 1-(4-sulfonic acid) butyl-3-methylimidazolium hydrogen sulfate ([BSMim]HSO₄) with addition of water at 120°C for 120 min (Table 6, entry 1) [348]. The ILs demonstrated a dual solvent-acid role for the direct synthesis of LA from cellulose. More recently, Sun et al. reported a good temperature-responsive heteropolycyclic (HPA) catalyst (CH₄AlW₁₂O₄₀) prepared using H₃AlW₁₂O₄₀ and choline chloride as raw materials, and when it was used for the one-pot conversion of cellulose into LA in a green cosolvent MIBK/H₂O with a volumetric ratio of 10: 1, leading to the highest LA yield with 74.8% at 98.9% cellulose conversion at 120°C for 10 h compared with other reported catalysts (Table 6, entry 2) [349]. The excellent catalytic activity of CH₄AlW₁₂O₄₀ was due to three synergistic effects of temperature stimulus, double-acidity property (Lewis and Brønsted acidity), and bif即使是 solvent inclusion system including MIBK and H₂O.

Khan et al. synthesized a dicationic IL catalyst [C₄(Mim)₂][2(HSO₄)(H₂SO₄)] including 1,1-bis(3-methylimidazolium-1-yl) butylene ([C₄(Mim)₂]) cation with counter anions hydrogensulfate, dihydrogensulfate, methanesulfonate, and trifluoromethanesulfonate, which was used for the direct conversion of cellulose into LA, resulting in 55% LA yield in H₂O at 100°C for 3 h, which was demonstrated to be a better catalytic activity than other reported ILs (Table 6, entry 3) [350]. The excellent yield of [C₄(Mim)₂][2(HSO₄)(H₂SO₄)] was attributed to higher Hammett acidity of the prepared ILs including more acidic sites in the HSO₄ anion.

Most recently, Chiappe et al. reported one-pot synthesis of LA from CFP (a cellulose from filter paper) by using 0.375 wt% TiOSO₄ as a catalyst, in which the highest 69% yield of LA was obtained in H₂O at 195°C for 4 h compared with other catalysts, such as (TMGH)(HSO₄)-CrCl₃ in H₂O, (TMGH)(HSO₄)-CrCl₃ in H₂O-CO₂, and FeCl₃ in H₂O (Table 6, entry 4) [351]. The excellent performance of 0.375 wt% TiOSO₄ was mainly due to the mixed Bronsted-Lewis acid catalytic system.

Yu et al. reported an efficient sulfonated hyperbranched poly(arylene oxindole)s with 5-chloro-substituent group polymer acid catalyst (5-Cl-SHPAOs), and when it was applied for the catalytic conversion of cellulose into LA in H₂O, the LA yield was up to 50% at 165°C for 5 h, which was twice as high as unsubstituted SHPAOs (Table 6, entry 5) [352].

A novel hierarchically porous ETS-10-supported Ni catalyst (5.0 wt% Ni-HMET-10) was prepared by Xiang et al., and when it was used for the catalytic conversion of cellulose to LA in aqueous solution, a high yield of LA with 91.0% was achieved at 200°C for 6 h under 6.0 MPa of H₂ pressure. An excellent catalytic activity of 5.0 wt% Ni-HMET-10 for the conversion of cellulose to LA was attributed to the synergistic effect of Lewis acid sites and unique hierarchical porous structures centered at 16 nm in ETS-10 in a H₂ atmosphere (Table 6, entry 6) [353].
3.5. Lactic Acid. Lactic acid is an important organic acid, which is also a key platform molecule in the biobased economy. Lactic acid and its derivatives have been used in many fields, such as food, medicine, cosmetics, and other industries. Highly selective catalytic transformation of cellulose into lactic acid has become a hot and difficult issue in recent years [354–357].

Deng et al. reported a bifunctional Al(III)-Sn(II) catalyst with a molar ratio of 1/1, which was applied for the catalytic conversion of cellulose and related carbohydrates to lactic acid, resulting in as high as 65% lactic acid yield in H2O at 189.85°C for 2 h under 3.0 MPa of N2 pressure (Table 7, entry 1) [358]. The bifunctional catalyst exhibited an excellent lactic acid yield because the combination of Al(III) and Sn(II) cations promoted the catalytic conversion of cellulose to lactic acid and limited the side reaction.

A series of erbium ion-exchanged montmorillonite K10 catalysts were prepared by Wang et al. and used as solid acid catalysts for the conversion of cellulose to lactic acid. Interestingly, Er/K10(S)-3 exhibited the highest yield of lactic acid with 67.6% in aqueous solution at 240°C for 30 min under 2.0 MPa of N2 pressure (Table 7, entry 2) [359]. Following this work, Wang et al. reported a series of Er/β-zeolite catalysts prepared using erbium species grafted on β-zeolites, which were used for one-pot hydrothermal transformation of cellulose to lactic acid [360]. 57.9% lactic acid yield was achieved over the 12.4 wt% Er/deAlb-2 catalyst (synthesized by erbium species grafted on de-aluminated β-zeolite) with a Si/Al ratio of 159 for the conversion of cellulose into lactic acid in H2O at 240°C for 30 min under 2.0 MPa of N2 pressure (Table 7, entry 3). The excellent activity of Er/deAlb-2 might be due to its higher erbium content, larger average pore diameter, and external surface area, which promoted contact between active erbium ions and reactant molecules.

Wattanapaphawong et al. studied the effect of a large number of transition metal oxides on the catalytic activity of cellulose conversion to lactic acid. They found that ZRO-7 exhibited the highest yield of lactic acid from cellulose with 21.2% in H2O at 199.85°C for 6 h compared with transition metal oxide catalysts, such as Al2O3, V2O5, CeO2, Y2O3, Ga2O3, and MgO (Table 7, entry 4) [361]. The remarkable catalytic activity of ZRO-7 was due to the large amount of base and acid sites on the ZRO-7 catalyst. Following this work, the 10%ZrO2-Al2O3 catalyst synthesized by Wattanapaphawong et al. was used for the production of lactic acid from cellulose, leading to 25.3% lactic acid yield at 199.85°C for 6 h in aqueous solution (Table 7, entry 5), which was superior to ZRO-7 [362]. Compared to pure ZrO2, the ZrO2-Al2O3 catalysts contained more Lewis acid sites and fewer base sites. The researchers suggested that the Lewis acid sites on ZrO2-Al2O3 play a more important role than do basic sites for the production of lactic acid from cellulose.

| Entry | Substrate | Solvent | Catalyst | Pretreatment | T°C | t/min | Yield/% | Ref. |
|-------|-----------|---------|----------|--------------|-----|-------|---------|------|
| 1     | Cellulose | H2O     | Al(III)-Sn(II) | Ball-milling | 189.85 | 120   | 65.0 | [358] |
| 2     | MCC       | H2O     | Er/K10(S)-3 | Mechanical stirrer | 240 | 30 | 67.6 | [359] |
| 3     | MCC       | H2O     | Er/deAlb-2 | Mechanical stirrer | 240 | 30 | 57.9 | [360] |
| 4     | MCC       | H2O     | ZRO-7 ZrO2 | Ball-milling | 199.85 | 360 | 21.2 | [361] |
| 5     | MCC       | H2O     | 10%ZrO2-Al2O3 | Ball-milling | 199.85 | 360 | 25.3 | [362] |

4. Conclusions

Direct chemocatalytic conversion of lignocellulosic biomass to renewable and value-added chemicals has attracted worldwide attention in order to build up sustainable societies. Cellulose is the most abundant, renewable, and nonedible biomass resource in lignocellulosic biomass. However, the recalcitrance and low reactivity of cellulose have hampered its sustainability and cost-effective utilization for chemical industry except for papermaking. It has been expected that homogeneous or heterogeneous catalysts for the direct chemocatalytic conversion of cellululosic biomass into high-value platform chemicals can overcome this problem due to the fact that various types of pretreatment as well as homogeneous or heterogeneous catalysts can be designed and applied under a wide range of reaction conditions. In this review, we have summarized the recent pretreatment methods for decreasing the rigid structure of cellulose and catalytic conversion of cellulose into key platform chemicals, such as glucose, ethylene glycol, sorbitol, 5-hydroxymethylfurural, levulinic acid, and lactic acid, via a variety of homogeneous or heterogeneous catalysts. This work will be helpful for researchers to build a deeper understanding of existing chemical processes on the value-added utilization of cellulose biomass to high-value chemicals and rationally design a more efficient chemical catalytic conversion system for cellulose biomass.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

This work was supported by the State Key Laboratory of Tree Genetics and Breeding (K2017101), Foundation of Jiangsu Provincial Key Laboratory of Pulp and Paper Science and Technology (no. 201531), the State Key Laboratory of Pulp and Paper Engineering (201822), National Natural Science Foundation of China (NSFC, U1407204, 51503148, U1707602), and Tianjin Research Program of Application Foundation and Advanced Technology (15JQNJ09000).
References

[1] Z. Sun, B. Fridrich, A. de Santi, S. Elangovan, and K. Barta, “Bright side of lignin depolymerization: toward new platform chemicals,” *Chemical Reviews*, vol. 118, no. 2, pp. 614–678, 2018.

[2] K. Ullah, V. K. Sharma, M. Ahmad et al., “The insight views of advanced technologies and its application in bio-origin fuel synthesis from lignocellulose biomasses waste, a review,” *Renewable & Sustainable Energy Reviews*, vol. 82, pp. 3992–4008, 2018.

[3] A. J. Ragauskas, C. K. Williams, B. H. Davison et al., “The path forward for biofuels and biomaterials,” *Science*, vol. 311, no. 5760, pp. 484–489, 2006.

[4] N. D. Fitzgerald, “Chemistry challenges to enable a sustainable bioeconomy,” *Nature Reviews Chemistry*, vol. 1, no. 10, article 0080, 2017.

[5] D. W. Wakerley, M. F. Kuehnel, K. L. Orchard, K. H. Ly, T. E. Rossier, and E. Reisner, “Solar-driven reforming of lignocellulose to H2 with a CdS/CdOx photocatalyst,” *Nature Energy*, vol. 2, no. 4, article 17021, 2017.

[6] J. S. Luterbacher, J. M. Rand, D. M. Alonso et al., “Nonenzymatic sugar transformation from biomass using biomass-derived y-valerolactone,” *Science*, vol. 343, no. 6168, pp. 277–280, 2014.

[7] Z. Zhang and G. W. Huber, “Catalytic oxidation of carbohydrates into organic acids and furan chemicals,” *Chemical Society Reviews*, vol. 47, no. 4, pp. 1351–1390, 2018.

[8] X. Li, T. Guo, Q. Xia, X. Liu, and Y. Wang, “One-pot catalytic transformation of lignocellulosic biomass into alkylcyclohexanes and polyols,” *ACS Sustainable Chemistry & Engineering*, vol. 6, no. 3, pp. 4390–4399, 2018.

[9] Z. Zhang, J. Song, and B. Han, “Catalytic transformation of lignocellulose into chemicals and fuel products in ionic liquids,” *Chemical Reviews*, vol. 117, no. 10, pp. 6834–6880, 2017.

[10] S. Zhu, J. Guo, X. Wang, J. Wang, and W. Fan, “Alcoholysis: a promising technology for conversion of lignocellulose and platform chemicals,” *ChemSusChem*, vol. 10, no. 12, pp. 2547–2559, 2017.

[11] J. Han, “Process systems engineering studies for catalytic production of bio-based platform molecules from lignocellulosic biomass,” *Energy Conversion and Management*, vol. 138, pp. 511–517, 2017.

[12] H. Li, A. Rissanen, S. Saravanamurugan et al., “Carbon-increasing catalytic strategies for upgrading biomass into energy-intensive fuels and chemicals,” *ACS Catalysis*, vol. 8, no. 1, pp. 148–187, 2018.

[13] G. Kabir and B. H. Hameed, “Recent progress on catalytic pyrolysis of lignocellulosic biomass to high-grade bio-oil and bio-chemicals,” *Renewable & Sustainable Energy Reviews*, vol. 70, pp. 945–967, 2017.

[14] W. Leitner, J. Klankermayer, S. Pischinger, H. Pitsch, and K. Kohse-Höinghaus, “Advanced biofuels and beyond: chemistry solutions for propulsion and production,” *Angewandte Chemie*, vol. 56, no. 20, pp. 5412–5452, 2017.

[15] T. Renders, S. van den Bosch, S. F. Koeliewijn, W. Schutyser, and B. F. Sels, “Lignin-first biomass fractionation: the advent of active stabilisation strategies,” *Energy & Environmental Science*, vol. 10, no. 7, pp. 1551–1557, 2017.

[16] D. M. Alonso, S. H. Hakim, S. Zhou et al., “Increasing the revenue from lignocellulosic biomass: maximizing feedstock utilization,” *Science Advances*, vol. 3, no. 5, article e1603301, 2017.

[17] R. Rinaldi, R. Jastrzebski, M. T. Clough et al., “Paving the way for lignin valorisation: recent advances in bioengineering, biorefining and catalysis,” *Angewandte Chemie*, vol. 55, no. 29, pp. 8164–8215, 2016.

[18] L. T. Mika, E. Cséfalvay, and Á. Németh, “Catalytic conversion of carbohydrates to initial platform chemicals: chemistry and sustainability,” *Chemical Reviews*, vol. 118, no. 2, pp. 505–613, 2018.

[19] J. Pan, Y. Mao, H. Gao et al., “Fabrication of hydrophobic polymer foams with double acid sites on surface of macropore for conversion of carbohydrate,” *Carbohydrate Polymers*, vol. 143, pp. 212–222, 2016.

[20] Q. Hou, W. Li, M. Zhen et al., “An ionic liquid-organic solvent biphasic system for efficient production of 5-hydroxymethylfurfural from carbohydrates at high concentrations,” *RSC Advances*, vol. 7, no. 75, pp. 47288–47296, 2017.

[21] L. Hu, G. Zhao, X. Tang et al., “Catalytic conversion of carbohydrates into 5-hydroxymethylfurfural over cellulose-derived carbonaceous catalyst in ionic liquid,” *Bioresource Technology*, vol. 148, pp. 501–507, 2013.

[22] R. Zhong, F. Yu, W. Schutyser et al., “Acidic mesostructured silica-carbon nanocomposite catalysts for biofuels and chemicals synthesis from sugars in alcoholic solutions,” *Applied Catalysis B: Environmental*, vol. 206, pp. 74–88, 2017.

[23] L. Jiang, L. Zhou, J. Chao et al., “Direct catalytic conversion of carbohydrates to methyl levulinate: synergy of solid Brønsted acid and Lewis acid,” *Applied Catalysis B: Environmental*, vol. 220, pp. 589–596, 2018.

[24] M. Wang, J. Ma, H. Liu, N. Luo, Z. Zhao, and F. Wang, “Sustainable productions of organic acids and their derivatives from biomass via selective oxidative cleavage of C-C bond,” *ACS Catalysis*, vol. 8, no. 3, pp. 2129–2165, 2018.

[25] H. Li, Z. Fang, R. L. Smith Jr, and S. Yang, “Efficient valorization of biomass to biofuels with bifunctional solid catalytic materials,” *Progress in Energy and Combustion Science*, vol. 55, pp. 98–194, 2016.

[26] M. Shaikh, S. K. Singh, S. Khilar, M. Sahu, and K. V. S. Ranganath, “Graphene oxide as a sustainable metal and solvent free catalyst for dehydration of fructose to 5-HMF: a new and green protocol,” *Catalysis Communications*, vol. 106, pp. 64–67, 2018.

[27] H. Wu, J. Song, C. Xie, C. Wu, C. Chen, and B. Han, “Efficient and mild transfer hydrogenolytic cleavage of aromatic ether bonds in lignin-derived compounds over Ru/C,” *ACS Sustainable Chemistry & Engineering*, vol. 6, no. 3, pp. 2872–2877, 2018.

[28] A. Das, A. Rahimi, A. Ulbrich et al., “Lignin conversion to low-molecular-weight aromatics via an aerobic oxidation-hydrolysis sequence: comparison of different lignin sources,” *ACS Sustainable Chemistry & Engineering*, vol. 6, no. 3, pp. 3367–3374, 2018.

[29] I. Bodachivskyi, U. Kuzhiumparambil, and D. B. G. Williams, “Acid-catalyzed conversion of carbohydrates into value-added small molecules in aqueous media and ionic liquids,” *ChemSusChem*, vol. 11, no. 4, pp. 642–660, 2018.
X. Yang, H. S. Choi, C. Park, and S. W. Kim, 
“Encapsulation of ultrafine metal-oxide nanoparticles within mesopores for biomass-derived catalytic applications,” Chemical Science, vol. 9, no. 7, pp. 1854–1859, 2018.

L. Liu, Z. Li, W. Hou, and H. Shen, “Direct conversion of lignocellulose to levulinic acid catalyzed by ionic liquid,” Carbohydrate Polymers, vol. 181, pp. 778–784, 2017.

M. Pelckmans, W. Vermandel, F. van Waes, K. Moonen, and B. F. Sels, “Low-temperature reductive aminolysis of carbohydrates to diamines and aminoalcohols by heterogenously catalytic,” Angewandte Chemie, vol. 56, no. 46, pp. 14540–14544, 2017.

X. Li, Q. Liu, C. Luo, X. Gu, L. Lu, and X. Lu, “Kinetics of furfural production from corn cob in γ-valerolactone using dilute sulfuric acid as catalyst,” ACS Sustainable Chemistry & Engineering, vol. 5, no. 10, pp. 8587–8593, 2017.

X. Li, Q. Liu, C. Si et al., “Green and efficient production of furfural from corn cob over H-ZSM-5 using γ-valerolactone as solvent,” Industrial Crops and Products, vol. 120, pp. 343–350, 2018.

L. Capolupo and V. Faraco, “Green methods of lignocellulose pretreatment for biofinery development,” Applied Microbiology and Biotechnology, vol. 100, no. 22, pp. 9451–9467, 2016.

J. Xu, J. Xu, S. Zhang et al., “Synergistic effects of metal salt and ionic liquid on the pretreatment of sugarcane bagasse for enhanced enzymatic hydrolysis,” Bioresource Technology, vol. 249, pp. 1058–1061, 2018.

H. Guo, Y. Chang, and D.-J. Lee, “Enzymatic saccharification of lignocellulosic biofinery: research focuses,” Bioresource Technology, vol. 252, pp. 198–215, 2018.

S. Wang, G. Dai, H. Yang, and Z. Luo, “Lignocellulosic biomass pyrolysis mechanism: a state-of-the-art review,” Progress in Energy and Combustion Science, vol. 62, pp. 33–86, 2017.

X. Yang, H. S. Choi, C. Park, and S. W. Kim, “Current states and prospects of organic waste utilization for biofinery,” Renewable & Sustainable Energy Reviews, vol. 49, pp. 335–349, 2015.

J. C. Serrano-Ruiz, R. Luque, and A. Sepulveda-Escribano, “Transformations of biomass-derived platform molecules: from high added-value chemicals to fuels via aqueous-phase processing,” Chemical Society Reviews, vol. 40, no. 11, pp. 5266–5281, 2011.

H. Zhang, Y.-T. Cheng, T. P. Vispute, R. Xiao, and G. W. Huber, “Catalytic conversion of biomass-derived feedstocks into olefins and aromatics with ZSM-5: the hydrogen to carbon effective ratio,” Energy & Environmental Science, vol. 4, no. 6, pp. 2297–2307, 2011.

C. Chatterjee, F. Pong, and A. Sen, “Chemical conversion pathways for carbohydrates,” Green Chemistry, vol. 17, no. 1, pp. 40–71, 2015.

D. P. Serrano, J. A. Melero, G. Morales, J. Iglesias, and P. Pizarro, “Progress in the design of zeolite catalysts for biomass conversion into biofuels and bio-based chemicals,” Catalysis Reviews-Science and Engineering, vol. 60, no. 1, pp. 1–70, 2018.

L. Dai, R. Liu, and C. Si, “A novel functional lignin-based filler for pyrolysis and feedstock recycling of poly(L-lactide),” Green Chemistry, vol. 20, no. 8, pp. 1777–1783, 2018.

H. Tadesse and R. Luque, “Advances on biomass pretreatment using ionic liquids: an overview,” Energy & Environmental Science, vol. 4, no. 10, pp. 3913–3929, 2011.

H. T. C. Leung, K. R. Maas, R. C. Wilhelm, and W. W. Mohn, “Long-term effects of timber harvesting on hemi-cellulosic microbial populations in coniferous forest soils,” The ISME Journal, vol. 10, no. 2, pp. 363–375, 2016.

D. W. Rackemann and W. O. S. Doherty, “The conversion of lignocellulosics to levulinic acid,” Biofuels, Bioproducts and Biorefining, vol. 5, no. 2, pp. 198–214, 2011.

M. B. Comba, Y. H. Tsai, A. M. Sarotti, M. I. Mangione, A. G. Suárez, and R. A. Spanevello, “Levoglucosanone and its new applications: valorization of cellulose residues,” European Journal of Organic Chemistry, vol. 2018, no. 5, pp. 590–604, 2018.

H. Wang, Y. Guo, C. Chang et al., “Enhancing tungsten oxide/SBA-15 catalysts for hydrolysis of cellobiose through doping ZrO2,” Applied Catalysis: A, General, vol. 523, pp. 182–192, 2016.

A. Charmot, P.-W. Chung, and A. Katz, “Catalytic hydrolysis of cellulose to glucose using weak-acid surface sites on post-synthetically modified carbon,” ACS Sustainable Chemistry & Engineering, vol. 2, no. 12, pp. 2866–2872, 2014.

J. B. Binder and R. T. Raines, “Fermentable sugars by chemical hydrolysis of biomass,” Proceedings of the National Academy of Sciences of the United States of America, vol. 107, no. 10, pp. 4516–4521, 2010.

F. Tao, H. Song, and L. Chou, “Hydrolysis of cellulose by using catalytic amounts of FeCl3 in ionic liquids,” ChemSusChem, vol. 3, no. 11, pp. 1298–1303, 2010.

J. Pang, A. Wang, M. Zheng, and T. Zhang, “Hydrolysis of cellulose into glucose over carbons sulfonated at elevated temperatures,” Chemical Communications, vol. 46, no. 37, pp. 6935–6937, 2010.

R. Palkovits, K. Tajvidi, A. M. Ruppert, and J. Procelevska, “Heteropoly acids as efficient acid catalysts in the one-step conversion of cellulose to sugar alcohols,” Chemical Communications, vol. 47, no. 1, pp. 576–578, 2011.

R. A. Sheldon, “Green and sustainable manufacture of chemicals from biomass: state of the art,” Green Chemistry, vol. 16, no. 3, pp. 950–963, 2014.

S. Shen, C. Wang, Y. Han, B. Cai, and H. Li, “Influence of reaction conditions on heterogeneous hydrolysis of cellulose over phenolic residue-derived solid acid,” Fuel, vol. 134, pp. 573–578, 2014.

J. González-Rivera, I. R. Galindo-Esquível, M. Onor, E. Bramanti, I. Longo, and C. Ferrari, “Heterogeneous catalytic reaction of microcrystalline cellulose in hydrothermal microwave-assisted decomposition: effect of modified zeolite Beta,” Green Chemistry, vol. 16, no. 3, pp. 1417–1425, 2014.

E. M. Rubin, “Genomics of cellulogenic biofuels,” Nature, vol. 454, no. 7206, pp. 841–845, 2008.

J. L. W. Morgan, J. T. McNamara, and J. Zimmer, “Mechanism of activation of bacterial cellulose synthase by cyclic di-GMP,” Nature Structural & Molecular Biology, vol. 21, no. 5, pp. 489–496, 2014.
[61] D. M. Updegraff, “Semimicro determination of cellulose in biological materials,” *Analytical Biochemistry*, vol. 32, no. 3, pp. 420–424, 1969.

[62] K. Tashiro and M. Kobayashi, “Theoretical evaluation of three-dimensional elastic constants of native and regenerated celluloses: role of hydrogen bonds,” *Polymer*, vol. 32, no. 8, pp. 1516–1526, 1991.

[63] Y. Marechal and H. Chanzy, “The hydrogen bond network in β cellulose as observed by infrared spectrometry,” *Journal of Molecular Structure*, vol. 523, no. 1-3, pp. 183–196, 2000.

[64] B. Hinterstoisser, M. Akerholm, and L. Salmen, “Load distribution in native cellulose,” *Biomacromolecules*, vol. 4, no. 5, pp. 1232–1237, 2003.

[65] Z. Jiang, P. Zhao, and C. Hu, “Controlling the cleavage of the inter- and intra-molecular linkages in lignocellulosic biomass for further bio-refining: a review,” *Bioresource Technology*, vol. 256, pp. 466–477, 2018.

[66] R. J. Moon, A. Martini, J. Nairn, J. Simonsen, and J. Youngblood, “Cellulose nanomaterials review: structure, properties and nanocomposites,” *Chemical Society Reviews*, vol. 40, no. 7, pp. 3941–3994, 2011.

[67] M. Sasaki, T. Adschiri, and K. Arai, “Cellulose nanomaterials review: structure, properties and nanocomposites,” *Chemical Society Reviews*, vol. 40, no. 7, pp. 3941–3994, 2011.

[68] Q. Xu, C. Chen, K. Rosswurm, T. Yao, and S. Janaswamy, “A facile route to prepare cellulose-based films,” *Carbohydrate Polymers*, vol. 149, pp. 274–281, 2016.

[69] F. Muratore, R. E. Martini, and S. E. Barbosa, “Bioactive paper by eugenol grafting onto cellulose. Effect of reaction variables,” *Food Packaging and Shelf Life*, vol. 15, pp. 159–168, 2018.

[70] K. M. Gupta, Q. Shi, L. Sarkisov, and J. Jiang, “Ethanolamine purification by nanofiltration through PIM-1 and carbon membranes: a molecular simulation study,” *The Journal of Physical Chemistry C*, vol. 121, no. 37, pp. 20539–20545, 2017.

[71] N. M. Julkapli and S. Bagheri, “Progress on nanocrystalline cellulose biocomposites,” *Reactive and Functional Polymers*, vol. 112, pp. 9–21, 2017.

[72] K. M. Gupta and J. Jiang, “Cellulose dissolution and regeneration in ionic liquids: a computational perspective,” *Chemical Engineering Science*, vol. 121, pp. 180–189, 2015.

[73] Y. Habibi, L. A. Lucia, and O. J. Rojas, “Cellulose nanocrystals: chemistry, self-assembly, and applications,” *Chemical Reviews*, vol. 110, no. 6, pp. 3479–3500, 2010.

[74] J. M. A. R. Almeida, L. da Viá, P. Demma Carà et al., “Screening of mono- and bi-functional catalysts for the one-pot conversion of cellulose into sorbitol,” *Catalysis Today*, vol. 279, pp. 187–193, 2017.

[75] D. Trache, M. H. Hussin, M. K. M. Haafiz, and V. K. Thakur, “Recent progress in cellulose nanocrystals: sources and production,” *Nanoscale*, vol. 9, no. 5, pp. 1763–1786, 2017.

[76] T. Li, C. Zhang, K.-L. Yang, and J. He, “Unique genetic cassettes in a *Thermoanaerobacterium* contribute to simultaneous conversion of cellulose and monosugars into butanol,” *Science Advances*, vol. 4, no. 3, article e1701475, 2018.

[77] N. Shi, Q. Liu, Q. Zhang, T. Wang, and L. Ma, “High yield production of 5-hydroxymethylfurfural from cellulose by high concentration of sulfates in biphasic system,” *Green Chemistry*, vol. 15, no. 7, pp. 1967–1974, 2013.

[78] X. Tang, H. Chen, L. Hu et al., “Conversion of biomass to y-valerolactone by catalytic transfer hydrogenation of ethyl levulate over metal hydroxides,” *Applied Catalysis B: Environmental*, vol. 147, pp. 827–834, 2014.

[79] P. L. Dhepe and A. Fukuoka, “Cellulose conversion under heterogeneous catalysis,” *ChemSusChem*, vol. 1, no. 12, pp. 969–975, 2008.

[80] J. A. Geboers, S. van de Vyver, R. Ooms, B. op de Beeck, P. A. Jacobs, and B. F. Sels, “Chemocatalytic conversion of cellulose: opportunities, advances and pitfalls,” *Catalysis Science & Technology*, vol. 1, no. 5, pp. 714–726, 2011.

[81] S. Morales-DelaRosa, J. M. Campos-Martin, and J. L. Fierro, “Chemical hydrolysis of cellulose into fermentable sugars through ionic liquids and antisolvent pretreatments using heterogeneous catalysts,” *Catalysis Today*, vol. 302, pp. 87–93, 2018.

[82] K. I. Galikin, E. A. Krivodova, L. V. Romashov et al., “Critical influence of 5-hydroxymethylfurfural aging and decomposition on the utility of biomass conversion in organic synthesis,” *Angewandte Chemie*, vol. 55, no. 29, pp. 8338–8342, 2016.

[83] H. Zhang, H. Pan, and S. Yang, “Upgrading of cellulose to biofuels and chemicals with acidic nanocatalysts,” *Current Nanoscience*, vol. 13, no. 5, pp. 513–527, 2017.

[84] L. Hu, X. Tang, J. Xu, Z. Wu, L. Lin, and S. Liu, “Selective transformation of 5-hydroxymethylfurfural into the liquid fuel 2,5-dimethylfuran over carbon-supported rhenium,” *Industrial & Engineering Chemistry Research*, vol. 53, no. 8, pp. 3056–3064, 2014.

[85] A. Fukuoka and P. L. Dhepe, “Catalytic conversion of cellulose into sugar alcohols,” *Angewandte Chemie*, vol. 45, no. 31, pp. 5161–5165, 2006.

[86] Y. Wang, W. Deng, B. Wang et al., “Chemical synthesis of lactic acid from cellulose catalysed by lead(II) ions in water,” *Nature Communications*, vol. 4, no. 1, p. 2141, 2013.

[87] Y. B. Huang, T. Yang, Y. T. Lin, Y. Z. Zhu, L. C. Li, and H. Pan, “Facile and high-yield synthesis of methyl levulinate from cellulose,” *Green Chemistry*, vol. 20, no. 6, pp. 1323–1334, 2018.

[88] A. Wang and T. Zhang, “One-pot conversion of cellulose to ethylene glycol with multifunctional tungsten-based catalysts,” *Accounts of Chemical Research*, vol. 46, no. 7, pp. 1377–1386, 2013.

[89] Y. Zhao, M. Zheng, R. Sun et al., “Ethylene glycol production from glucose over W-Ru catalysts: maximizing yield by kinetic modeling and simulation,” *AIChE Journal*, vol. 63, no. 6, pp. 2072–2080, 2017.

[90] G. Xu, A. Wang, J. Pang et al., “Chemocatalytic conversion of cellulose biomass to methyl glycolate, ethylene glycol, and ethanol,” *ChemSusChem*, vol. 10, no. 7, pp. 1390–1394, 2017.

[91] K.-i. Shimizu and A. Satsuma, “Toward a rational control of solid acid catalysis for green synthesis and biomass conversion,” *Energy & Environmental Science*, vol. 4, no. 9, pp. 3140–3153, 2011.

[92] H. Kobayashi, T. Komanoya, S. K. Guha, K. Haru, and A. Fukuoka, “Conversion of cellulose into renewable chemicals by supported metal catalysis,” *Applied Catalysis A: General*, vol. 409–410, pp. 13–20, 2011.

[93] S. Van de Vyver, J. Geboers, P. A. Jacobs, and B. F. Sels, “Recent advances in the catalytic conversion of cellulose,” *ChemCatChem*, vol. 3, no. 1, pp. 82–94, 2011.
A multitechnique approach to assess the effect of ball milling on cellulose, *Carbohydrate Polymers*, vol. 87, no. 1, pp. 265–273, 2012.

M. Ago, T. Endo, and T. Hirotsu, “Crystalline transformation of native cellulose from cellulose I to cellulose II polymorph by a ball-milling method with a specific amount of water,” *Cellulose*, vol. 11, no. 2, pp. 163–167, 2004.

X. Li, Y. Jiang, L. Shuai, L. Wang, L. Meng, and X. Mu, “Sulfonated copolymers with SO3H and COOH groups for the hydrolysis of polysaccharides,” *Journal of Materials Chemistry*, vol. 22, no. 4, pp. 1283–1289, 2012.

G. Gliozzi, A. Innorota, A. Mancini et al., “Zr/PtO catalyst for the direct acid chemo-hydrolysis of non-pretreated microcrystalline cellulose and softwood sawdust,” *Applied Catalysis B: Environmental*, vol. 145, pp. 24–33, 2014.

A. Onda, T. Ochi, and K. Yamasaki, “Selective hydrolysis of cellulose into glucose over solid acid catalysts,” *Green Chemistry*, vol. 10, no. 10, pp. 1033–1037, 2008.

S. Van de Vyver, L. Peng, J. Geboers et al., “Sulfonated silica/carbon nanocomposites as novel catalysts for hydrolysis of cellulose to glucose,” *Green Chemistry*, vol. 12, no. 9, pp. 1560–1563, 2010.

H. Kobayashi, T. Komanoya, K. Hara, and A. Fukuoaka, “Water-tolerant mesoporous-carbon-supported ruthenium catalysts for the hydrolysis of cellulose to glucose,” *ChemSusChem*, vol. 3, no. 4, pp. 440–443, 2010.

C. Zhang, H. Wang, F. Liu, L. Wang, and H. He, “Magnetic core–shell Fe3O4@C–SO3H nanoparticle catalyst for hydrolysis of cellulose,” *Cellulose*, vol. 20, no. 1, pp. 127–134, 2013.

G. Akiyama, R. Matsuda, H. Sato, M. Takata, and S. Kitagawa, “Cellulose hydrolysis by a new porous coordination polymer decorated with sulfonic acid functional groups,” *Advanced Materials*, vol. 23, no. 29, pp. 3294–3297, 2011.

H. Kobayashi, M. Yabushita, T. Komanoya, K. Hara, I. Fujita, and A. Fukuoaka, “High-yielding one-pot synthesis of glucose from cellulose using simple activated carbons and trace hydrochloric acid,” *ACS Catalysis*, vol. 3, no. 4, pp. 581–587, 2013.

T. Suzuki and H. Nakagami, “Effect of crystallinity of microcrystalline cellulose on the compactability and dissolution of tablets,” *European Journal of Pharmaceutics and Biopharmaceutics*, vol. 47, no. 3, pp. 225–230, 1999.

A. Kafy, H. C. Kim, L. Zhai et al., “Cellulose long fibers fabricated from cellulose nanofibers and its strong and tough characteristics,” *Scientific Reports*, vol. 7, no. 1, article 17683, 2017.

F. Rol, B. Karakashov, O. Nechyporchuk et al., “Pilot-scale twin screw extrusion and chemical pretreatment as an energy-efficient method for the production of nanofibrillated cellulose at high solid content,” *ACS Sustainable Chemistry & Engineering*, vol. 5, no. 8, pp. 6524–6531, 2017.

W. Deng, X. Tan, W. Fang, Q. Zhang, and Y. Wang, “Conversion of cellulose into sorbitol over carbon nanotubebased ruthenium catalyst,” *Catalysis Letters*, vol. 133, no. 1–2, pp. 167–174, 2009.

J. Strachan, “Solubility of cellulose in water,” *Nature*, vol. 141, no. 3564, pp. 332–333, 1938.

Z. Fang and J. A. Kozinski, “Phase behavior and combustion of hydrocarbon-contaminated sludge in supercritical water at pressures up to 822 MPa and temperatures up to 535°C,” *Proceedings of the Combustion Institute*, vol. 28, no. 2, pp. 2717–2725, 2000.

H. Zhao, J. Kwak, Y. Wang, J. Franz, J. White, and J. Holladay, “Interactions between cellulose and N-methylmorphpoline-N-oxide,” *Carbohydrate Polymers*, vol. 67, no. 1, pp. 97–103, 2007.

W. Burchard, N. Habermann, P. Klüfers, B. Seger, and U. Wilhelm, “Cellulose in Schweizer’s reagent: a stable, polymeric metal complex with high chain stiffness,” *Angewandte Chemie*, vol. 33, no. 8, pp. 884–887, 1994.

C. L. McCormick, P. A. Callais, and B. H. Hutchinson, “Solution studies of cellulose in lithium chloride and N, N-dimethylacetamide,” *Macromolecules*, vol. 18, no. 12, pp. 2394–2401, 1985.

R. Lavanya, I. Clara, and N. Natchimuthu, “Shear-induced morphology changes in N, N′-dimethylacetamide/lithium chloride pretreated cellulose,” *Journal of Applied Polymer Science*, vol. 134, no. 19, article 44809, 2017.

T. Röder, B. Morgenstern, N. Schelosky, and O. Glatter, “Solution of cellulose in N,N-dimethylacetamide/lithium chloride studied by light scattering methods,” *Polymer*, vol. 42, no. 16, pp. 6765–6773, 2001.

S. Peleteiro, S. Rivas, J. L. Alonso, V. Santos, and J. C. Parajo, “Utilization of ionic liquids in lignocellulosic biorefineries as agents for separation, derivatization, fractionation, or pretreatment,” *Journal of Agricultural and Food Chemistry*, vol. 63, no. 7, pp. 8093–8102, 2015.

D. L. Minnick, R. A. Flores, M. R. DeStefano, and A. M. Scurto, “Cellulose solubility in ionic liquid mixtures: temperature, cosolvent, and antisolvent effects,” *Journal of Physical Chemistry B*, vol. 120, no. 32, pp. 7906–7919, 2016.

S. Zhu, Y. Wu, Q. Chen et al., “Dissolution of cellulose with ionic liquids and its application: a mini-review,” *Green Chemistry*, vol. 8, no. 4, pp. 325–327, 2006.

S. Morales-del-Rosa, J. M. Campos-Martín, and J. L. G. Fierro, “High glucose yields from the hydrolysis of cellulose dissolved in ionic liquids,” *Chemical Engineering Journal*, vol. 181–182, pp. 538–541, 2012.

A. Kamimura, T. Okagawa, N. Oyama, T. Otsuka, and M. Yoshimoto, “Combination use of hydrophobic ionic liquids and LiCl as a good reaction system for the chemical conversion of cellulose to glucose,” *Green Chemistry*, vol. 14, no. 10, pp. 2816–2820, 2012.

R. C. Remsing, R. P. Swatloski, R. D. Rogers, and G. Moyna, “Mechanism of cellulose dissolution in the ionic liquid 1-n-butyl-3-methylimidazolium chloride: a 13C and 35/37Cl NMR relaxation study on model systems,” *Chemical Communications*, no. 12, pp. 1271–1273, 2006.

J. F. Brennecke and E. J. Maginn, “Ionic liquids: innovative fluids for chemical processing,” *AIChE Journal*, vol. 47, no. 11, pp. 2384–2389, 2001.
[155] R. D. Rogers and K. R. Seddon, “Ionic liquids–solvents of the future?” Science, vol. 302, no. 5646, pp. 792-793, 2003.

[156] N. V. Plechkova and K. R. Seddon, “Applications of ionic liquids in the chemical industry,” Chemical Society Reviews, vol. 37, no. 1, pp. 123–150, 2008.

[157] R. P. Swatloski, S. K. Spear, J. D. Holbrey, and R. D. Rogers, “Dissolution of cellulose with ionic liquids,” Journal of the American Chemical Society, vol. 124, no. 18, pp. 4974-4975, 2002.

[158] H. Wang, G. Gurau, and R. D. Rogers, “Ionic liquid processing of cellulose,” Chemical Society Reviews, vol. 41, no. 4, pp. 1519–1537, 2012.

[159] C. Li and Z. K. Zhao, “Efficient acid-catalyzed hydrolysis of cellulose in ionic liquid,” Advanced Synthesis & Catalysis, vol. 349, no. 11-12, pp. 1847–1850, 2007.

[160] Y. Li, X. Liu, Y. Zhang, K. Jiang, J. Wang, and S. Zhang, “Why only ionic liquids with unsaturated heterocyclic cations can dissolve cellulose: a simulation study,” ACS Sustainable Chemistry & Engineering, vol. 5, no. 4, pp. 3417–3428, 2017.

[161] Y. Li, J. Wang, X. Liu, and S. Zhang, “Towards a molecular understanding of cellulose dissolution in ionic liquids: anion/cation effect, synergistic mechanism and physicochemical aspects,” Chemical Science, vol. 9, no. 17, pp. 4027–4043, 2018.

[162] R. Rinaldi and F. Schüth, “Acid hydrolysis of cellulose as the entry point into biorefinery schemes,” ChemSusChem, vol. 2, no. 12, pp. 1096–1107, 2009.

[163] D.-m. Lai, L. Deng, J. Li, B. Liao, Q. X. Guo, and Y. Fu, “Hydrolysis of cellulose into glucose by magnetic solid acid,” ChemSusChem, vol. 4, no. 1, pp. 55–58, 2011.

[164] H. Guo, Y. Lian, L. Yan, X. Qi, and R. L. Smith, “Cellulose-derived superparamagnetic carbonaceous solid acid catalyst for cellulose hydrolysis in an ionic liquid or aqueous reaction system,” Green Chemistry, vol. 15, no. 8, pp. 2167–2174, 2013.

[165] X. Li, Y. Jiang, L. Wang, L. Meng, W. Wang, and X. Mu, “Effective low-temperature hydrolysis of cellulose catalyzed by concentrated H₃PW₁₂O₴₀ under microwave irradiation,” RSC Advances, vol. 2, no. 17, pp. 6921–6925, 2012.

[166] D. A. Cantero, M. Dolores Bermejo, and M. Jose Cocero, “High glucose selectivity in pressurized water hydrolysis of cellulose using ultra-fast reactors,” Biotechnology, vol. 135, pp. 697–703, 2013.

[167] J. Tian, J. Wang, S. Zhao, C. Jiang, X. Zhang, and X. Wang, “Hydrolysis of cellulose by the heteropoly acid H₃PW₁₂O₴₀,” Cellulose, vol. 17, no. 3, pp. 587–594, 2010.

[168] J. Wang, J. Xi, and Y. Wang, “Recent advances in the catalytic production of glucose from lignocellulosic biomass,” Green Chemistry, vol. 17, no. 2, pp. 737–751, 2015.

[169] R. Palkovits, K. Tajvidi, J. Procelewska, R. Rinaldi, and A. Ruppert, “Hydrogenolysis of cellulose combining mineral acids and hydrogenation catalysts,” Green Chemistry, vol. 12, no. 6, pp. 972–978, 2010.

[170] A. M. Orozco, A. H. al-Muhtaseb, A. B. Albadarin, D. Rooney, G. M. Walker, and M. N. M. Ahmad, “Acid-catalyzed hydrolysis of cellulose and cellulose waste using a microwave reactor system,” RSC Advances, vol. 1, no. 5, pp. 839–846, 2011.

[171] C. Li, Q. Wang, and Z. K. Zhao, “Acid in ionic liquid: an efficient system for hydrolysis of lignocellulose,” Green Chemistry, vol. 10, no. 2, pp. 177–182, 2008.

[172] J. Fan, M. de bruyn, Z. Zhu et al., “Microwave-enhanced formation of glucose from cellulosic waste,” Chemical Engineering and Processing, vol. 71, pp. 37–42, 2013.

[173] Q. Xiang, Y. Y. Lee, P. O. Pettersson, and R. W. Torget, “Heterogeneous aspects of acid hydrolysis of α-cellulose,” Applied Biochemistry and Biotechnology, vol. 105, pp. 505–514, 2003.

[174] Q. Pang, L. Wang, H. Yang, L. Jia, X. Pan, and C. Qiu, “Cellulose-derived carbon bearing -Cl and -SO₃H groups as a highly selective catalyst for the hydrolysis of cellulose to glucose,” RSC Advances, vol. 4, no. 78, pp. 41212–41218, 2014.

[175] K. Intaramas, W. Jonglertjunya, N. Laosiripojana, and C. Sakkaranon, “Selective conversion of cassava mash to glucose using solid acid catalysts by sequential solid state mixed-milling reaction and thermo-hydrolysis,” Energy, vol. 149, pp. 837–847, 2018.

[176] F. Shen, R. L. Smith Jr, L. Li, L. Yan, and X. Qi, “Eco-friendly method for efficient conversion of cellulose into levulinic acid in pure water with cellulase-mimetic solid acid catalyst,” ACS Sustainable Chemistry & Engineering, vol. 5, no. 3, pp. 2421–2427, 2017.

[177] J. Vitz, T. Erdmenger, C. Haensch, and U. S. Schubert, “Extended dissolution studies of cellulose in imidazolium based ionic liquids,” Green Chemistry, vol. 11, no. 3, pp. 417–424, 2009.

[178] K. Dong and S. Zhang, “Hydrogen bonds: a structural insight into ionic liquids,” Chemistry – A European Journal, vol. 18, no. 10, pp. 2748–2761, 2012.

[179] A. W. T. King, J. Asikkala, I. Mutikainen, P. Järvi, and I. Kilpeläinen, “Distillable acid–base conjugate ionic liquids for cellulose dissolution and processing,” Angewandte Chemie, vol. 50, no. 28, pp. 6301–6305, 2011.

[180] H. Zhang, J. Wu, J. Zhang, and J. He, “1-Alkyl-3-methylimidazolium chloride room temperature ionic liquid: a new and powerful nonderivatizing solvent for cellulose,” Macromolecules, vol. 38, no. 20, pp. 8272–8277, 2005.

[181] M. Završel, D. Bross, M. Funke, J. Buchs, and A. C. Spiess, “High-throughput screening for ionic liquids dissolving (ligno-)cellulose,” Bioresource Technology, vol. 100, no. 9, pp. 2580–2587, 2009.

[182] K. C. Badgujar and B. M. Bhanage, “Factors governing dissolution process of lignocellulosic biomass in ionic liquid: current status, overview and challenges,” Bioresource Technology, vol. 178, pp. 2–18, 2015.

[183] A. Xu, Y. Zhang, Y. Zhao, and J. Wang, “Cellulose dissolution at ambient temperature: role of preferential solvation of cations of ionic liquids by a cosolvent,” Carbohydrate Polymers, vol. 92, no. 1, pp. 540–544, 2013.

[184] R. Rinaldi, “Instantaneous dissolution of cellulose in organic electrolyte solutions,” Chemical Communications, vol. 47, no. 1, pp. 511–513, 2011.

[185] N. Sun, H. Rodríguez, M. Rahman, and R. D. Rogers, “Where are ionic liquid strategies most suited in the pursuit of chemicals and energy from lignocellulosic biomass?” Chemical Communications, vol. 47, no. 5, pp. 1405–1421, 2011.

[186] C.-Z. Liu, F. Wang, A. R. Stiles, and C. Guo, “Ionic liquids for biofuel production: opportunities and challenges,” Applied Energy, vol. 92, pp. 406–414, 2012.

[187] T. Heineke, K. Schwikal, and S. Barthel, “Ionic liquids as reaction medium in cellulose functionalization,” Macromolecular Bioscience, vol. 5, no. 6, pp. 520–525, 2005.
A. S. Amarasekara and O. S. Owereh, "Predicting cellulose solvating capabilities of acid-base conjugate ionic liquids," ChemSusChem, vol. 6, no. 11, pp. 2161–2169, 2013.

D. G. Raut, O. Sundman, W. Su et al., "A morpholinium ionic liquid for cellulose dissolution," Carbohydrate Polymers, vol. 130, pp. 18–25, 2015.

P. Kubisa, "Ionic liquids as solvents for polymerization processes-progress and challenges," Progress in Polymer Science, vol. 34, no. 12, pp. 1333–1347, 2009.

Y. Zhang, H. du, X. Qian, and E. Y. X. Chen, "Ionic liquid–water mixtures: enhanced $K_a$ for efficient cellulose biomass conversion," Energy & Fuels, vol. 24, no. 4, pp. 2410–2417, 2010.

A. C. Cole, J. L. Jensen, I. Ntai et al., "Novel Brønsted acidic ionic liquids and their use as dual solvent-catalysts," Journal of the American Chemical Society, vol. 124, no. 21, pp. 5962–5963, 2002.

D. C. Forbes and K. J. Weaver, "Brønsted acidic ionic liquids: the dependence on water of the Fischer esterification of acetic acid and ethanol," Journal of Molecular Catalysis A: Chemical, vol. 214, no. 1, pp. 129–132, 2004.

A. S. Amarasekara and O. S. Owereh, "Hydrolysis and decomposition of cellulose in Brønsted acidic ionic liquids under mild conditions," Industrial & Engineering Chemistry Research, vol. 48, no. 22, pp. 10152–10155, 2009.

F. Parveen, M. Jaiswal, and S. Upadhyayula, "Effect of linkers (aliphatic/aromatic) and anions on the activity of sulfonic acid functionalized ionic liquids towards catalyzing the hydrolysis of microcrystalline cellulose-an experimental and theoretical study," Renewable Energy, vol. 121, pp. 590–596, 2018.

P. Lu, Z. P. Zhao, X. Y. Wang, G. J. Lan, and X. L. Wang, "Understanding effect of molecular structure of imidazole-based ionic liquids on catalytic performance for biomass inulin hydrolysis," Molecular Catalysis, vol. 435, pp. 24–32, 2017.

A. M. da Costa Lopes and R. Bogel-Lukasik, "Acidic ionic liquids as sustainable approach of cellulose and lignocellulosic biomass conversion without additional catalysts," ChemSusChem, vol. 8, no. 6, pp. 947–965, 2015.

A. S. Amarasekara and O. S. Owereh, "Synthesis of a sulfonyl acid functionalized acidic ionic liquid modified silica catalyst and applications in the hydrolysis of cellulose," Catalysis Communications, vol. 11, no. 13, pp. 1072–1075, 2010.

P. Sarma, A. K. Dutta, and R. Borah, "Design and exploration of $SO_3H$ group functionalized Brønsted acidic ionic liquids (BAILs) as task-specific catalytic systems for organic reactions: a review of literature," Catalysis Surveys from Asia, vol. 21, no. 2, pp. 70–93, 2017.

A. S. Amarasekara, "Acidic ionic liquids," Chemical Reviews, vol. 116, no. 10, pp. 6133–6183, 2016.

K. Zhuo, Q. du, G. Bai, C. Wang, Y. Chen, and J. Wang, "Hydrolysis of cellulose catalyzed by novel acidic ionic liquids," Carbohydrate Polymers, vol. 115, pp. 49–53, 2015.

F. Parveen, T. Patra, and S. Upadhyayula, "Hydrolysis of microcrystalline cellulose using functionalized Bronsted acidic ionic liquids - a comparative study," Carbohydrate Polymers, vol. 135, pp. 280–284, 2016.

A. S. Amarasekara and B. Wiredu, "Degradation of cellulose in dilute aqueous solutions of acidic ionic liquid 1-(1-propyl-sulfonic)-3-methylimidazolium chloride, and p-toluenesulfonic acid at moderate temperatures and pressures," Industrial & Engineering Chemistry Research, vol. 50, no. 21, pp. 12276–12280, 2011.

Y. Liu, W. Xiao, S. Xia, and P. Ma, "$SO_3H$-functionalized acidic ionic liquids as catalysts for the hydrolysis of cellulose," Carbohydrate Polymers, vol. 92, no. 1, pp. 218–222, 2013.

C.-H. Zhou, X. Xia, C.-X. Lin, D. S. Tong, and J. Beltrami, "Catalytic conversion of lignocellulosic biomass to fine chemicals and fuels," Chemical Society Reviews, vol. 40, no. 11, pp. 5588–5617, 2011.

H. Satria, K. Kuroda, T. Endo, K. Takada, K. Ninomiya, and K. Takahashi, "Efficient hydrolysis of polysaccharides in bagasse by in situ synthesis of an acidic ionic liquid after pre-treatment," ACS Sustainable Chemistry & Engineering, vol. 5, no. 1, pp. 708–713, 2017.

F. Jiang, D. Ma, and X. Bao, "Acid ionic liquid catalyzed hydrolysis of cellulose," Chinese Journal of Catalysis, vol. 30, no. 4, pp. 279–283, 2009.

B. Wiredu and A. S. Amarasekara, "Synthesis of a silica-immobilized Brønsted acidic ionic liquid catalyst and hydrolysis of cellulose in water under mild conditions," Catalysis Communications, vol. 48, pp. 41–44, 2014.

C. Zhang, Z. Fu, B. Dai et al., "Biochar sulfonic acid immobilized chlorozincate ionic liquid: an efficiently biomimetic and reusable catalyst for hydrolysis of cellulose and bamboo under microwave irradiation," Cellulose, vol. 21, no. 3, pp. 1227–1237, 2014.

H. Olivier-Bourbigou, L. Magna, and D. Morvan, "Ionic liquids and catalysis: recent progress from knowledge to applications," Applied Catalysis A: General, vol. 373, no. 1-2, pp. 1–56, 2010.

A. Brandt, J. Gräsäv, J. P. Hallett, and T. Welton, "Deconstruction of lignocellulosic biomass with ionic liquids," Green Chemistry, vol. 15, no. 3, pp. 550–583, 2013.

Q. Zhang, S. Zhang, and Y. Deng, "Recent advances in ionic liquid catalysis," Green Chemistry, vol. 13, no. 10, pp. 2619–2637, 2011.

Z. Sun, M. Cheng, H. Li et al., "One-pot depolymerization of cellulose into glucose and levulinic acid by heteropolyacid ionic liquid catalysis," RSC Advances, vol. 2, no. 24, pp. 9058–9065, 2012.

K. Kuroda, K. Miyamura, H. Satria, K. Takada, K. Ninomiya, and K. Takahashi, "Hydrolysis of cellulose using an acidic and hydrophobic liquid and subsequent separation of glucose aqueous solution from the ionic liquid and 5-(hydroxymethyl)furfural," ACS Sustainable Chemistry & Engineering, vol. 4, no. 6, pp. 3352–3356, 2016.

F. Jiang, Q. Zhu, D. Ma, X. Liu, and X. Han, "Direct conversion and NMR observation of cellulose to glucose and 5-hydroxymethylfurfural (HMF) catalyzed by the acidic ionic liquids," Journal of Molecular Catalysis A: Chemical, vol. 334, no. 1-2, pp. 8–12, 2011.

F. Parveen, K. Gupta, and S. Upadhyayula, "Synergistic effect of chloro and sulfonic acid groups on the hydrolysis of microcrystalline cellulose under benign conditions," Carbohydrate Polymers, vol. 159, pp. 146–151, 2017.

Y. Xiong, Z. Zhang, X. Wang, B. Liu, and J. Lin, "Hydrolysis of cellulose in ionic liquids catalyzed by a magnetically-recoverable solid acid catalyst," Chemical Engineering Journal, vol. 235, pp. 349–355, 2014.
[218] M. Hara, K. Nakajima, and K. Kamata, “Recent progress in the development of solid catalysts for biomass conversion into high value-added chemicals,” Science and Technology of Advanced Materials, vol. 16, no. 3, article 034903, 2015.

[219] N. V. Gromov, O. P. Taran, V. S. Semyekina et al., “Solid acidic NbOx/ZrO2 catalysts for transformation of cellulose to glucose and 5-hydroxymethylfurfural in pure hot water,” Catalysis Letters, vol. 147, no. 6, pp. 1485–1495, 2017.

[220] J. Su, M. Qiu, F. Shen, and X. Qi, “Efficient hydrolysis of cellulose to glucose in water by agricultural residue-derived solid acid catalyst,” Cellulose, vol. 25, no. 1, pp. 17–22, 2018.

[221] M. Tyukelchiv, P. Duan, K. Schmidt-Rohr, S. Granados Foci, M. T. Timko, and M. H. Emmert, “Cellulase-inspired solid acids for cellulose hydrolysis: structural explanations for high catalytic activity,” ACS Catalysis, vol. 8, no. 2, pp. 1464–1468, 2018.

[222] R. Rinaldi, R. Palkovits, and F. Schüth, “Depolymerization of cellulose using solid catalysts in ionic liquids,” Angewandte Chemie, vol. 47, no. 42, pp. 8047–8050, 2008.

[223] R. Rinaldi and F. Schüth, “Design of solid catalysts for the conversion of biomass,” Energy & Environmental Science, vol. 2, no. 6, pp. 610–626, 2009.

[224] Y. B. Huang and Y. Fu, “Hydrolysis of cellulose to glucose by solid acid catalysts,” Green Chemistry, vol. 15, no. 5, pp. 1095–1111, 2013.

[225] Y. Gu and G. Li, “Ionic liquids-based catalysis with solids: state of the art,” Advanced Synthesis & Catalysis, vol. 351, no. 6, pp. 817–847, 2009.

[226] R. Rinaldi, N. Meine, J. vom Stein, R. Palkovits, and F. Schüth, “Which controls the depolymerization of cellulose in ionic liquids: the solid acid catalyst or cellulose?,” ChemSusChem, vol. 3, no. 2, pp. 266–276, 2010.

[227] Z. Zhang and Z. K. Zhao, “Solid acid and microwave-assisted hydrolysis of cellulose in ionic liquid,” Carbohydrate Research, vol. 344, no. 15, pp. 2069–2072, 2009.

[228] M. Liu, S. Jia, Y. Gong, C. Song, and X. Guo, “Effective hydrolysis of cellulose into glucose over sulfonated sugar-derived carbon in an ionic liquid,” Industrial & Engineering Chemistry Research, vol. 52, no. 24, pp. 8167–8173, 2013.

[229] Q. Yang and X. Pan, “Bifunctional porous polymers bearing boronic and sulfonic acids for hydrolysis of cellulose,” ACS Sustainable Chemistry & Engineering, vol. 4, no. 9, pp. 4824–4830, 2016.

[230] M. Zhang, M. Wu, Q. Liu, X. Wang, T. Lv, and L. Jia, “Graphene oxide mediated cellulose-derived carbon as a highly selective catalyst for the hydrolysis of cellulose to glucose,” Applied Catalysis A: General, vol. 543, pp. 218–224, 2017.

[231] Z. Yang, R. Huang, W. Qi, L. Tong, R. Su, and Z. He, “Hydrolysis of cellulose by sulfonated magnetic reduced graphene oxide,” Chemical Engineering Journal, vol. 280, pp. 90–98, 2015.

[232] F. Atabaki, A. Abedini, and A. Shokorlaei, “Efficient hydrolysis of cellulose into glucose over sulfonated polynaphthalene (SPN) and rapid determination of glucose using positive corona discharge ion mobility spectrometry,” RSC Advances, vol. 6, no. 10, pp. 7879–7885, 2016.

[233] O. L. Li, R. Ikura, and T. Ishizaki, “Hydrolysis of cellulose to glucose over carbon catalysts sulfonated via a plasma process in dilute acids,” Green Chemistry, vol. 19, no. 20, pp. 4774–4777, 2017.

[234] E. G. Mission, A. T. Quitain, M. Sasaki, and T. Kida, “Synergizing graphene oxide with microwave irradiation for efficient cellulose depolymerization into glucose,” Green Chemistry, vol. 19, no. 16, pp. 3831–3843, 2017.

[235] J. Yu, J. Y. Wang, Z. Wang, M. D. Zhou, and H. Y. Wang, “Hydrolysis of cellulose promoted by silicalite-1 modified HY zeolite in 1-ethyl-3-methylimidazolium chloride,” Cellulose, vol. 25, no. 3, pp. 1607–1615, 2018.

[236] H. Kobayashi, Y. Ito, T. Komanoya et al., “Synthesis of sugar alcohols by hydrolytic hydrogenation of cellulose over supported metal catalysts,” Green Chemistry, vol. 13, no. 2, pp. 326–333, 2011.

[237] B. Zada, M. Chen, C. Chen et al., “Recent advances in catalytic production of sugar alcohols and their applications,” Science China Chemistry, vol. 60, no. 7, pp. 853–869, 2017.

[238] J. Chen, S. Wang, J. Huang, L. Chen, L. Ma, and X. Huang, “Conversion of cellulose and cellubiose into sorbitol catalyzed by ruthenium supported on a poloyoxometalate/metal-organic framework hybrid,” ChemSusChem, vol. 6, no. 8, pp. 1545–1555, 2013.

[239] X. Liu, X. Wang, S. Yao, Y. Jiang, J. Guan, and X. Mu, “Recent advances in the production of polyols from lignocellulosic biomass and biomass-derived compounds,” RSC Advances, vol. 4, no. 90, pp. 49501–49520, 2014.

[240] M. Zheng, J. Pang, R. Sun, A. Wang, and T. Zhang, “Selectivity control for cellulose to diols: dancing on eggs,” ACS Catalysis, vol. 7, no. 3, pp. 1939–1954, 2017.

[241] C. Luo, S. Wang, and H. Liu, “Cellulose conversion into polyols catalyzed by reversibly formed acids and supported ruthenium clusters in hot water,” Angewandte Chemie, vol. 46, no. 40, pp. 7636–7639, 2007.

[242] Z. Xiao, J. Mao, C. Jiang, C. Xing, J. Ji, and Y. Cheng, “One-pot selective conversion of cellulose into low carbon polyols on nano-Sn based catalysts,” Journal of Renewable and Sustainable Energy, vol. 9, no. 2, article 024703, 2017.

[243] S. Van de Vyver, J. Geboers, M. Dusselier et al., “Selective bifunctional catalytic conversion of cellulose over reshaped Ni particles at the tip of carbon nanofibers,” ChemSusChem, vol. 3, no. 6, pp. 698–701, 2010.

[244] T. Deng and H. Liu, “Promoting effect of SnO2 on selective conversion of cellulose to polyols over bimetallic Pt-SnO2/Al2O3 catalysts,” Green Chemistry, vol. 15, no. 1, pp. 116–124, 2013.

[245] L. S. Ribeiro, J. J. Delgado, J. J. de Melo Órfão, and M. F. R. Pereira, “Direct conversion of cellulose to sorbitol over ruthenium catalysts: influence of the support,” Catalysis Today, vol. 279, pp. 244–251, 2017.

[246] R. Sun, M. Zheng, J. Pang et al., “Selectivity-switchable conversion of cellulose to glycols over Ni-Sn catalysts,” ACS Catalysis, vol. 6, no. 1, pp. 191–201, 2016.

[247] H. Liu, L. Qin, X. Wang, C. du, D. Sun, and X. Meng, “Hydrolytic hydro-conversion of cellulose to ethylene glycol over bimetallic Cu/Al2O3 catalysts,” Catalysis Communications, vol. 77, pp. 47–51, 2016.

[248] P. Kosem, A. Hejna, K. Formela, J. T. Haponiuk, and L. Piszczyk, “Biopolymers obtained via crude glycerol-based liquefaction of cellulose: their structural, rheological and thermal characterization,” Cellulose, vol. 23, no. 5, pp. 2929–2942, 2016.

[249] L. Yang, X. Yan, Q. Wang, Q. Wang, and H. Xia, “One-pot catalytic conversion of cellulose into polyols with Pt/
CNTs catalysts,” *Carbohydrate Research*, vol. 404, pp. 87–92, 2015.

[250] K. Fabiòvicová, M. Lucas, and P. Claus, “From microcrystalline cellulose to hard- and softwood-based feedstocks: their hydrolysis to polyols over a highly efficient ruthenium-tungsten catalyst,” *Green Chemistry*, vol. 17, no. 5, pp. 3075–3083, 2015.

[251] K. Tajvidi, P. J. C. Hausoul, and R. Palkovits, ”Hydrogenolysis of cellulose over Cu-based catalysts—analysis of the reaction network,” *ChemSusChem*, vol. 7, no. 5, pp. 1311–1317, 2014.

[252] R. Ooms, M. Dusselier, J. A. Geboers et al., “Conversion of sugars to ethylene glycol with nickel tungsten carbide in a fed-batch reactor: high productivity and reaction network elucidation,” *Green Chemistry*, vol. 16, no. 2, pp. 695–707, 2014.

[253] O. V. Manaenkov, V. G. Matveeva, E. M. Sulman et al., “Ru-containing polymeric catalysts for cellulose conversion to polyols,” *Topics in Catalysis*, vol. 57, no. 17–20, pp. 1476–1482, 2014.

[254] T. Komanoya, H. Kobayashi, K. Hara, W. J. Chun, and A. Fukuoka, ”Kinetic study of catalytic conversion of cellulose to sugar alcohols under low-pressure hydrogen,” *ChemCatChem*, vol. 6, no. 1, pp. 230–236, 2014.

[255] H. Kobayashi, Y. Hosaka, K. Hara, B. Feng, Y. Hirotsaki, and A. Fukuoka, ”Control of selectivity, activity and durability of simple supported nickel catalysts for hydrolytic hydrogenation of cellulose,” *Green Chemistry*, vol. 16, no. 2, pp. 637–644, 2014.

[256] K. Fabiòvicová, O. Malter, M. Lucas, and P. Claus, ”Hydrogenolysis of cellulose to valuable chemicals over activated carbon supported mono- and bimetallic nickel/tungsten catalysts,” *Green Chemistry*, vol. 16, no. 7, pp. 3580–3588, 2014.

[257] T. Deng and H. Liu, ”Direct conversion of cellulose into acetol on bimetallic Ni-SnO2/Al2O3 catalysts,” *Journal of Molecular Catalysis A: Chemical*, vol. 388-389, pp. 66–73, 2014.

[258] S. J. You, I. G. Baek, and E. D. Park, ”Hydrogenolysis of cellulose into polyols over Ni/W/SiO2 catalysts,” *Applied Catalysis A: General*, vol. 466, pp. 161–168, 2013.

[259] Z. Xiao, S. Jin, M. Pang, and C. Liang, ”Conversion of highly concentrated cellulose to 1,2-propanediol and ethylene glycol over highly efficient CuCr catalysts,” *Green Chemistry*, vol. 15, no. 4, pp. 891–895, 2013.

[260] H. Wang, L. Zhu, S. Peng, F. Peng, H. Yu, and J. Yang, ”High efficient conversion of cellulose to polyols with Ru/CNTs as catalyst,” *Renewable Energy*, vol. 37, no. 1, pp. 192–196, 2012.

[261] A. Shrottri, A. Tankesale, J. N. Beltramini, H. Gurav, and S. V. Chilukuri, ”Conversion of cellulose to polyols over promoted nickel catalysts,” *Catalysis Science & Technology*, vol. 2, no. 9, pp. 1852–1858, 2012.

[262] T. Deng, J. Sun, and H. Liu, ”Cellulose conversion to polyols on supported Ru catalysts in aqueous basic solution,” *Science China Chemistry*, vol. 53, no. 7, pp. 1476–1480, 2010.

[263] N. Ji, T. Zhang, M. Zheng et al., ”Catalytic conversion of cellulose into ethylene glycol over supported carbide catalysts,” *Catalysis Today*, vol. 147, no. 2, pp. 77–85, 2009.

[264] M. Y. Zheng, A. Q. Wang, N. Ji, J. F. Pang, X. D. Wang, and T. Zhang, ”Transition metal-tungsten bimetallic catalysts for the conversion of cellulose into ethylene glycol,” *ChemSusChem*, vol. 3, no. 1, pp. 63–66, 2010.

[265] Y. Zhang, A. Wang, and T. Zhang, ”A new 3D mesoporous carbon replicated from commercial silica as a catalyst support for direct conversion of cellulose into ethylene glycol,” *Chemical Communications*, vol. 46, no. 6, pp. 862–864, 2010.

[266] N. Ji, T. Zhang, M. Zheng et al., ”Direct catalytic conversion of cellulose into ethylene glycol using nickel-promoted tungsten carbide catalysts,” *Angewandte Chemie*, vol. 120, no. 44, pp. 8638–8641, 2008.

[267] Z. Tai, J. Zhang, A. Wang, J. Pang, M. Zheng, and T. Zhang, ”Catalytic conversion of cellulose to ethylene glycol over a low-cost binary catalyst of Raney Ni and tungstic acid,” *ChemSusChem*, vol. 6, no. 4, pp. 652–658, 2013.

[268] J. Xi, D. Ding, Y. Shao, X. Liu, G. Lu, and Y. Wang, ”Production of ethylene glycol and its mono-derivative from cellulose,” *ACS Sustainable Chemistry & Engineering*, vol. 2, no. 10, pp. 2355–2362, 2014.

[269] Y. Cao, J. Wang, M. Kang, and Y. Zhu, ”Efficient synthesis of ethylene glycol from cellulose over Ni-WO3/SBA-15 catalysts,” *Journal of Molecular Catalysis A: Chemical*, vol. 381, pp. 46–53, 2014.

[270] G. Xu, A. Wang, J. Pang, M. Zheng, J. Yin, and T. Zhang, ”Remarkable effect of extremely dilute H2SO4 on the cellulose conversion to ethylene glycol,” *Applied Catalysis A: General*, vol. 502, pp. 65–70, 2015.

[271] K. Zhang, S. Wu, H. Yang, H. Yin, and G. Li, ”Catalytic conversion of cellulose for efficient ethylene glycol production and insights into the reaction pathways,” *RSC Advances*, vol. 6, no. 81, pp. 77499–77506, 2016.

[272] R. De Clercq, M. Dusselier, and B. F. Sels, ”Heterogeneous catalysis for bio-based polyester monomers from cellulose biomass: advances, challenges and prospects,” *Green Chemistry*, vol. 19, no. 21, pp. 5012–5040, 2017.

[273] M. S. Hamdy, M. A. Eissa, and S. M. A. S. Keshk, ”New catalyst with multiple active sites for selective hydrogenolysis of cellulose to ethylene glycol,” *Green Chemistry*, vol. 19, no. 21, pp. 5144–5151, 2017.

[274] L. S. Ribeiro, J. Orfão, J. J. de Melo Orfão, and M. E. R. Pereira, ”Hydrolytic hydrogenation of cellulose to ethylene glycol over carbon nanotubes supported Ru-W bimetallic catalysts,” *Cellulose*, vol. 25, no. 4, pp. 2259–2272, 2018.

[275] Z. Xiao, Y. Fan, Y. Cheng et al., ”Metal particles supported on SiO2–OH nanosphere: new insight into interactions with metals for cellulose conversion to ethylene glycol,” *Fuel*, vol. 215, pp. 406–416, 2018.

[276] Y. Yang, W. Zhang, F. Yang et al., ”Versatile nickel-tungsten bimetallics/carbon nanofiber catalysts for direct conversion of cellulose to ethylene glycol,” *Green Chemistry*, vol. 18, no. 14, pp. 3949–3953, 2016.

[277] N. Li, Y. Zheng, L. Wei, H. Teng, and J. Zhou, ”Metal nanoparticles supported on WO3 nanosheets for highly selective hydrogenolysis of cellulose to ethylene glycol,” *Green Chemistry*, vol. 19, no. 3, pp. 682–691, 2017.

[278] L. N. Ding, A. Q. Wang, M. Y. Zheng, and T. Zhang, ”Selective transformation of cellulose into sorbitol by using a bifunctional nickel phosphide catalyst,” *ChemSusChem*, vol. 3, no. 7, pp. 818–821, 2010.

[279] D. Wang, W. Niu, M. Tan et al., ”Pt Nanocatalysts supported on reduced graphene oxide for selective conversion of...
cellulose or cellobiose to sorbitol,” ChemSusChem, vol. 7, no. 5, pp. 1398–1406, 2014.

[280] J. W. Han and H. Lee, “Direct conversion of cellulose into sorbitol using dual-functionalized catalysts in neutral aqueous solution,” Catalysis Communications, vol. 19, pp. 115–118, 2012.

[281] P. Yang, H. Kobayashi, K. Hara, and A. Fukuoka, “Phase change of nickel phosphide catalysts in the conversion of cellulose into sorbitol,” ChemSusChem, vol. 5, no. 5, pp. 920–926, 2012.

[282] A. Negoi, I. T. Trotus, O. Mamula Steiner et al., “Direct synthesis of sorbitol and glycerol from cellulose over ionic Ru/magnetite nanoparticles in the absence of external hydrogen,” ChemSusChem, vol. 6, no. 11, pp. 2090–2094, 2013.

[283] A. Negoi, K. Triantafyllidis, V. I. Parvulescu, and S. M. Coman, “The hydrolytic hydrogenation of cellulose to sorbitol over M (Ru, Ir, Pd, Rh)-BEA-zeolite catalysts,” Catalysis Today, vol. 223, pp. 122–128, 2014.

[284] L. S. Ribeiro, J. J. M. Órfão, and M. F. R. Pereira, “Comparative study of different catalysts for the direct conversion of cellulose to sorbitol,” Green Processing and Synthesis, vol. 4, no. 2, pp. 71–78, 2015.

[285] A. Romero, E. Alonso, A. Sastre, and A. Nieto-Márquez, “Conversion of biomass into sorbitol: cellulose hydrolysis on MCM-48 and D-glucose hydrogenation on Ru/MCM-48,” Microporous and Mesoporous Materials, vol. 224, pp. 1–8, 2016.

[286] L. S. Ribeiro, J. J. M. Órfão, and M. F. R. Pereira, “Simultaneous catalytic conversion of cellulose and corn cob xylan under temperature programming for enhanced sorbitol and xylitol production,” Bioresource Technology, vol. 244, pp. 1173–1177, 2017.

[287] L. S. Ribeiro, J. J. Delgado, J. J. de Melo Órfão, and M. F. Ribeiro Pereira, “Influence of the surface chemistry of multi-walled carbon nanotubes on the selective conversion of cellulose into sorbitol,” ChemCatChem, vol. 9, no. 5, pp. 888–896, 2017.

[288] J. Zhang, S. B. Wu, and Y. Liu, “Direct conversion of cellulose into sorbitol over a magnetic catalyst in an extremely low concentration acid system,” Energy & Fuels, vol. 28, no. 7, pp. 4242–4246, 2014.

[289] J. Xi, Y. Zhang, Q. Xia et al., “Direct conversion of cellulose into sorbitol with high yield by a novel mesoporous niobium phosphate supported ruthenium bifunctional catalyst,” Applied Catalysis A: General, vol. 459, pp. 52–58, 2013.

[290] W. Zhu, H. Yang, J. Chen et al., “Efficient hydrogenolysis of cellulose into sorbitol catalyzed by a bifunctional catalyst,” Green Chemistry, vol. 16, no. 3, pp. 1534–1542, 2014.

[291] L. S. Ribeiro, L. S. Ribeiro, J. J. M. Órfão, and M. F. R. Pereira, “Enhanced direct production of sorbitol by cellulose ball-milling,” Green Chemistry, vol. 17, no. 5, pp. 2973–2980, 2015.

[292] L. S. Ribeiro, J. J. Delgado, J. J. M. Órfão, and M. F. R. Pereira, “Carbon supported Ru-Ni bimetallic catalysts for the enhanced one-pot conversion of cellulose to sorbitol,” Applied Catalysis B: Environmental, vol. 217, pp. 265–274, 2017.

[293] J. J. Bozell and G. R. Petersen, “Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy’s “top 10” revisited,” Green Chemistry, vol. 12, no. 4, pp. 539–554, 2010.

[294] S. Verma, M. N. Nadagouda, and R. S. Varma, “Porous nitrogen-enriched carbonaceous material from marine waste: chitosan-derived carbon nitride catalyst for aerial oxidation of 5-hydroxymethylfurfural (HMF) to 2,5-furandicarboxylic acid,” Scientific Reports, vol. 7, no. 1, p. 15396, 2017.

[295] G. Li, Z. Sun, Y. Yan, Y. Zhang, and Y. Tang, “Direct transformation of HMF into 2,5-diformylfuran and 2,5-dihydroxymethylfuran without an external oxidant or reductant,” ChemSusChem, vol. 10, no. 3, pp. 494–498, 2017.

[296] F. A. Kucherov, K. I. Galkin, E. G. Gordeev, and V. P. Ananikov, “Efficient route for the construction of polycyclic systems from bioderived HMF,” Green Chemistry, vol. 19, no. 20, pp. 4858–4864, 2017.

[297] X. Qi, M. Watanabe, T. M. Aida, and R. L. Smith, “Catalytic conversion of cellulose into 5-hydroxymethylfurfural in high yields via a two-step process,” Cellulose, vol. 18, no. 5, pp. 1327–1333, 2011.

[298] S. P. Teong, G. Yi, and Y. Zhang, “Hydroxymethylfurfural production from biorefineries: past, present and future,” Green Chemistry, vol. 16, no. 4, pp. 2015–2026, 2014.

[299] A. Takagaki, M. Ohara, S. Nishimura, and K. Ebitani, “A one-pot reaction for biorefinery: combination of solid acid and base catalysts for direct production of 5-hydroxymethylfurfural from saccharides,” Chemical Communications, no. 41, pp. 6276–6278, 2009.

[300] C. Li, Z. Zhang, and Z. K. Zhao, “Direct conversion of glucose and cellulose to 5-hydroxymethylfurfural in ionic liquid under microwave irradiation,” Tetrahedron Letters, vol. 50, no. 38, pp. 5403–5405, 2009.

[301] T. Ståhlberg, W. Fu, J. M. Woodley, and A. Riisager, “Synthesis of 5-(hydroxymethyl) furfural in ionic liquids: paving the way to renewable chemicals,” ChemSusChem, vol. 4, no. 4, pp. 451–458, 2011.

[302] S. De, S. Dutta, and B. Saha, “Microwave assisted conversion of carbohydrates and biopolymers to 5-hydroxymethylfurfural with aluminium chloride catalyst in water,” Green Chemistry, vol. 13, no. 10, pp. 2859–2868, 2011.

[303] S. Zhao, M. Cheng, J. Li, J. Tian, and X. Wang, “One pot production of 5-hydroxymethylfurfural with high yield from cellulose by a Brønsted–Lewis–surfactant-combined heteropolyacid catalyst,” Chemical Communications, vol. 47, no. 7, pp. 2176–2178, 2011.

[304] P. Wang, H. Yu, S. Zhan, and S. Wang, “Catalytic hydrolysis of lignocellulosic biomass into 5-hydroxymethylfurfural in ionic liquid,” Bioresource Technology, vol. 102, no. 5, pp. 4179–4183, 2011.

[305] Y. Su, H. M. Brown, X. Huang, X. D. Zhou, J. E. Amontette, and Z. C. Zhang, “Single-step conversion of cellulose to 5-hydroxymethylfurfural (HMF) a versatile platform chemical,” Applied Catalysis A: General, vol. 361, no. 1-2, pp. 117–122, 2009.

[306] H. JadHAV, E. Taarning, C. M. Pedersen, and M. Bols, “Conversion of D-glucose into 5-hydroxymethylfurfural (HMF) using zeolite in [Bmim][Cl] or tetrabutylammonium chloride (TBAC)/CrCl₂,” Tetrahedron Letters, vol. 53, no. 8, pp. 983–985, 2012.

[307] L. Zhou, R. Liang, Z. Ma, T. Wu, and Y. Wu, “Conversion of cellulose to HMF in ionic liquid catalyzed by bifunctional ionic liquids,” Bioresource Technology, vol. 129, pp. 450–455, 2013.

[308] J. Zhou, Z. Xia, T. Huang et al., “An ionic liquid-organics–water ternary biphasic system enhances the 5-hydroxymethylfurfural yield in catalytic conversion of
glucose at high concentrations," Green Chemistry, vol. 17, no. 8, pp. 4206–4216, 2015.

[309] L. Hu, Z. Wu, J. Xu, Y. Sun, L. Lin, and S. Liu, “Zeolite-promoted transformation of glucose into 5-hydroxymethylfurfural in ionic liquid,” Chemical Engineering Journal, vol. 244, pp. 137–144, 2014.

[310] K. Y. Nandiwale, N. D. Galande, P. Thakur, S. D. Sawant, V. P. Zambre, and V. V. Bokade, “One-pot synthesis of 5-hydroxymethylfurfural by cellulose hydrolysis over highly active bimodal micro/mesoporous H-ZSM-5 catalyst,” ACS Sustainable Chemistry & Engineering, vol. 2, no. 7, pp. 1928–1932, 2014.

[311] N. Shi, Q. Liu, L. Ma et al., “Direct degradation of cellulose to 5-hydroxymethylfurfural in hot compressed steam with inorganic acidic salts,” RSC Advances, vol. 4, no. 10, pp. 4978–4984, 2014.

[312] G. R. Gomes, D. S. Rampon, and L. P. Ramos, “Production of furan compounds from sugarcane bagasse using a catalytic system containing ZnCl2/HCl or AlCl3/HCl in a biphasic system,” Journal of the Brazilian Chemical Society, vol. 29, no. 5, pp. 1115–1122, 2018.

[313] Y. Xuan, R. He, B. Han, T. Wu, and Y. Wu, “Catalytic conversion of cellulose into 5-hydroxymethylfurfural using [PSMIM]HSO4 and ZnSO4·7H2O co-catalyst in biphasic system,” Waste and Biomass Valorization, vol. 9, no. 3, pp. 401–408, 2018.

[314] R. Weingarten, A. Rodriguez-Beuerman, F. Cao et al., “Selective conversion of cellulose to hydroxymethylfurfural in polar aprotic solvents,” ChemCatChem, vol. 6, no. 8, pp. 2229–2234, 2014.

[315] S. Xiao, B. Liu, Y. Wang, Z. Fang, and Z. Zhang, “Efficient conversion of cellulose into biofuel precursor 5-hydroxymethylfurfural in dimethyl sulfoxide–ionic liquid mixtures,” Bioresource Technology, vol. 151, pp. 361–366, 2014.

[316] C. Chiappe, M. J. Rodriguez Douton, A. Mezzetta, C. S. Pernelli, G. Assanelli, and A. R. de Angelis, “Recycle and extraction: cornerstones for an efficient conversion of cellulose into 5-hydroxymethylfurfural in ionic liquids,” ACS Sustainable Chemistry & Engineering, vol. 5, no. 6, pp. 5529–5536, 2017.

[317] H. Xia, S. Xu, X. Yan, and S. Zuo, “High yield synthesis of 5-hydroxymethylfurfural from cellulose using FePO4 as the catalyst,” Fuel Processing Technology, vol. 152, pp. 140–146, 2016.

[318] Y. Shen, Y. Zhang, Y. Chen et al., “Combination of Brønsted and Lewis polymeric catalysts for efficient conversion of cellulose into 5-hydroxymethylfurfural (HMF) in ionic liquids,” Energy Technology, vol. 4, no. 5, pp. 600–609, 2016.

[319] B. B. Hewetson, X. Zhang, and N. S. Mosier, “Enhanced acid-catalyzed biomass conversion to hydroxymethylfurfural following cellulose solvent- and organic solvent-based lignocellulosic fractionation pretreatment,” Energy & Fuels, vol. 30, no. 11, pp. 9975–9977, 2016.

[320] L. Atanda, M. Konarova, Q. Ma, S. Mukundan, A. Shroti, and J. Beltramin, “High yield conversion of cellulose biomass into 5-hydroxymethylfurfural and a study of the reaction kinetics of cellulose to HMF conversion in a biphasic system,” Catalysis Science & Technology, vol. 6, no. 16, pp. 6257–6266, 2016.

[321] L. Zhou, Y. He, Z. Ma, R. Liang, T. Wu, and Y. Wu, “One-step degradation of cellulose to 5-hydroxymethylfurfural in ionic liquid under mild conditions,” Carbohydrate Polymers, vol. 117, pp. 694–700, 2015.

[322] Y. Zhang, J. Pan, Y. Shen, W. Shi, C. Liu, and L. Yu, “Brønsted acid polymer nanotubes with tunable wettability toward efficient conversion of one-pot cellulose to 5-hydroxymethylfurfural,” ACS Sustainable Chemistry & Engineering, vol. 3, no. 5, pp. 871–879, 2015.

[323] V. da Silva Lacera, J. B. López-Sotelo, A. Correa-Guimaraes et al., “A kinetic study on microwave-assisted conversion of cellulose and lignocellulosic waste into hydroxymethylfurfural/furfural,” Bioresource Technology, vol. 180, pp. 88–96, 2015.

[324] Y. Zhang, J. Pan, Y. Yan, W. Shi, and L. Yu, “Synthesis and evaluation of stable polymeric solid acid based on halloysite nanotubes for conversion of one-pot cellulose to 5-hydroxymethylfurfural,” RSC Advances, vol. 4, no. 45, pp. 23797–23806, 2014.

[325] Y. Zhang, J. Pan, M. Gan et al., “Acid-chromic chloride functionalized natural clay-particles for enhanced conversion of one-pot cellulose to 5-hydroxymethylfurfural in ionic liquids,” RSC Advances, vol. 4, no. 23, pp. 11664–11672, 2014.

[326] Y. Qu, Q. Wei, H. Li, P. Oleskowicz-Popiel, C. Huang, and J. Xu, “Microwave-assisted conversion of microcrystalline cellulose to 5-hydroxymethylfurfural catalyzed by ionic liquids,” Bioresource Technology, vol. 162, pp. 358–364, 2014.

[327] H. Abou-Yousef and E. B. Hassan, “A novel approach to enhance the activity of H-form zeolite catalyst for production of hydroxymethylfurfural from cellulose,” Journal of Industrial and Engineering Chemistry, vol. 20, no. 4, pp. 1952–1957, 2014.

[328] B. Liu, Z. Zhang, and Z. K. Zhao, “Microwave-assisted catalytic conversion of cellulose into 5-hydroxymethylfurfural in ionic liquids,” Chemical Engineering Journal, vol. 215–216, pp. 517–521, 2013.

[329] W.-H. Peng, Y.-Y. Lee, C. Wu, and K. C. W. Wu, “Acid-base bi-functionalized, large-pored mesoporous silica nanoparticles for cooperative catalysis of one-pot cellulose-to-HMF conversion,” Journal of Materials Chemistry, vol. 22, no. 43, pp. 23181–23185, 2012.

[330] P. Daoattanachai, P. Khemthong, N. Viriya-empikul, N. Laosiripojana, and K. Faungnawakij, “Conversion of fructose, glucose, and cellulose to 5-hydroxymethylfurfural by alkaline earth phosphate catalysts in hot compressed water,” Carbohydrate Research, vol. 363, pp. 58–61, 2012.

[331] Y. Zhang, P. Jin, M. Liu et al., “A novel route for green conversion of cellulose to HMF by cascading enzymatic and chemical reactions,” AICHE Journal, vol. 63, no. 11, pp. 4920–4932, 2017.

[332] B. Yuan, J. Guan, J. Peng, G. Z. Zhu, and J. H. Jiang, “Green hydrolysis of corn cob cellulose into 5-hydroxymethylfurfural using hydrophobic imidazole ionic liquids with a recyclable, magnetic metalloporphyrin catalyst,” Chemical Engineering Journal, vol. 330, pp. 109–119, 2017.

[333] Z. Li, K. Su, J. Ren et al., “Direct catalytic conversion of glucose and cellulose,” Green Chemistry, vol. 20, no. 4, pp. 863–872, 2018.

[334] X. Zhang, D. Zhang, Z. Sun, L. Xue, X. Wang, and Z. Jiang, “Highly efficient preparation of HMF from cellulose using temperature-responsive heteropolyacid catalysts in cascade
reaction,” *Applied Catalysis B: Environmental*, vol. 196, pp. 50–56, 2016.

[335] X. Bai, J. Y. Wang, N. Men, and S. L. Zang, “Degradation of microcrystalline cellulose to 5-hydroxymethylfurfural catalyzed by CrCl3/[R,N]ReO4,” *Catalysis Communications*, vol. 104, pp. 37–40, 2018.

[336] X. Li, K. Peng, Q. Xia, X. Liu, and Y. Wang, “Efficient conversion of cellulose into 5-hydroxyalkylfurans over niobia/ carbon composites,” *Chemical Engineering Journal*, vol. 332, pp. 528–536, 2018.

[337] Y. Zhao, S. Wang, H. Lin, J. Chen, and H. Xu, “Influence of a Lewis acid and a Brønsted acid on the conversion of microcrystalline cellulose into 5-hydroxymethylfurans in a single-phase reaction system of water and 1,2-dimethoxyethane,” *RSC Advances*, vol. 8, no. 13, pp. 7235–7242, 2018.

[338] J. J. Bozell, “Connecting biomass and petroleum processing with a chemical bridge,” *Science*, vol. 329, no. 5991, pp. 522–523, 2010.

[339] D. W. Rackemann and W. O. Doherty, “The conversion of lignocellulosics to levulinic acid,” *Biofuels, Bioproducts and Biorefining*, vol. 5, no. 2, pp. 198–214, 2011.

[340] L. Qi, Y. F. Mui, S. W. Lo, M. Y. Lui, G. R. Akien, and I. T. Horváth, “Catalytic conversion of fructose, glucose, and sucrose to 5-(hydroxymethyl) furfural and levulinic and formic acids in γ-valerolactone as a green solvent,” *ACS Catalysis*, vol. 4, no. 5, pp. 1470–1477, 2014.

[341] Y. Zuo, Y. Zhang, and Y. Fu, “Catalytic conversion of cellulose into levulinic acid by a sulfonated chloromethyl polystyrene solid acid catalyst,” *ChemCatChem*, vol. 6, no. 3, pp. 753–757, 2014.

[342] V. B. Kumar, I. N. Pulidindi, R. K. Mishra, and A. Gedanken, “Ga modified zeolite based solid acid catalyst for levulinic acid production,” *ChemistrySelect*, vol. 1, no. 18, pp. 5952–5960, 2016.

[343] K. Kumar, F. Parveen, T. Patra, and S. Upadhyayula, “Hydrothermal conversion of glucose to levulinic acid using multifunctional ionic liquids: effects of metal ion co-catalysts on the product yield,” *New Journal of Chemistry*, vol. 42, no. 1, pp. 228–236, 2018.

[344] X. Zhang, P. Murria, Y. Jiang et al., “Maleic acid and aluminosilicate catalyzed conversion of glucose to 5-(hydroxymethyl) furfural and levulinic acid in aqueous media,” *Green Chemistry*, vol. 18, no. 19, pp. 5219–5229, 2016.

[345] K. Qin, Y. Yan, Y. Zhang, and Y. Tang, “Direct production of levulinic acid in high yield from cellulose: joint effect of high ion strength and microwave field,” *RSC Advances*, vol. 6, no. 45, pp. 39131–39136, 2016.

[346] H. Ren, B. Girisuta, Y. Zhou, and L. Liu, “Selective and recyclable depolymerization of cellulose to levulinic acid catalyzed by acidic ionic liquid,” *Carbohydrate Polymers*, vol. 117, pp. 569–576, 2015.

[347] S. Van de Vyver, J. Thomas, J. Geboers et al., “Catalytic production of levulinic acid from cellulose and other biomass-derived carbohydrates with sulfonated hyperbranched poly(arylene oxindole),” *Energy & Environmental Science*, vol. 4, no. 9, pp. 3601–3610, 2011.

[348] Y. Shen, J.-K. Sun, Y.-X. Yi, B. Wang, F. Xu, and R. C. Sun, “One-pot synthesis of levulinic acid from cellulose in ionic liquids,” *Bioresource Technology*, vol. 192, pp. 812–816, 2015.

[349] Z. Sun, L. Xue, S. Wang, X. Wang, and J. Shi, “Single step conversion of cellulose to levulinic acid using temperature-responsive dodeca-alumino tungstic acid catalysts,” *Green Chemistry*, vol. 18, no. 3, pp. 742–752, 2016.

[350] A. S. Khan, Z. Man, M. A. Bustam et al., “Dicationic ionic liquids as sustainable approach for direct conversion of cellulose to levulinic acid,” *Journal of Cleaner Production*, vol. 170, pp. 591–600, 2018.

[351] C. Chiappe, M. J. Rodriguez Douton, A. Mezzetta et al., “Exploring and exploiting different catalytic systems for the direct conversion of cellulose into levulinic acid,” *New Journal of Chemistry*, vol. 42, no. 3, pp. 1845–1852, 2018.

[352] F. Yu, J. Thomas, M. Smet, W. Dehaen, and B. F. Sels, “Molecular design of sulfonated hyperbranched poly(arylene oxindole)s for efficient cellulose conversion to levulinic acid,” *Green Chemistry*, vol. 18, no. 6, pp. 1694–1705, 2016.

[353] M. Xiang, J. Liu, W. Fu, T. Tang, and D. Wu, “Improved activity for cellulose conversion to levulinic acid through hierarchization of ETS-10 zeolite,” *ACS Sustainable Chemistry & Engineering*, vol. 5, no. 7, pp. 5800–5809, 2017.

[354] H. Li, H.-F. Ren, B.-W. Zhao, C. L. Liu, R. Z. Yang, and W. S. Dong, “Production of lactic acid from cellulose catalyzed by alumina-supported Er2O3 catalysts,” *Research on Chemical Intermediates*, vol. 42, no. 9, pp. 7199–7211, 2016.

[355] S. M. Coman, M. Verziu, A. Tirsoaga et al., “NbF2-AlF3 catalysts: design, synthesis, and application in lactic acid synthesis from cellulose,” *ACS Catalysis*, vol. 5, no. 5, pp. 3013–3026, 2015.

[356] M. Dusselier, P. van Wouwe, A. Dewaele, E. Makshina, and B. F. Sels, “Lactic acid as a platform chemical in the biobased economy: the role of chemocatalysis,” *Energy & Environmental Science*, vol. 6, no. 5, pp. 1415–1442, 2013.

[357] F. Chambon, F. Rataboul, C. Pinel, A. Cabiac, E. Guillon, and N. Essayem, “Cellulose hydrothermal conversion promoted by heterogeneous Brønsted and Lewis acids: remarkable efficiency of solid Lewis acids to produce lactic acid,” *Applied Catalysis B: Environmental*, vol. 105, no. 1-2, pp. 171–181, 2011.

[358] W. Deng, P. Wang, B. Wang et al., “Transformation of cellulose and related carbohydrates into lactic acid with bifunctional Al(III)-Sn(II) catalysts,” *Green Chemistry*, vol. 20, no. 3, pp. 735–747, 2014.

[359] F. F. Wang, J. Liu, H. Li, C. L. Liu, R. Z. Yang, and W. S. Dong, “Conversion of cellulose to lactic acid catalyzed by erbritium-exchanged montmorillonite K10,” *Green Chemistry*, vol. 17, no. 4, pp. 2455–2463, 2015.

[360] F. F. Wang, H. Z. Wu, H. F. Ren, C. L. Liu, C. L. Xu, and W. S. Dong, “Er/β-zelite-catalyzed one-pot conversion of cellulose to lactic acid,” *Journal of Porous Materials*, vol. 24, no. 3, pp. 697–706, 2017.

[361] P. Wattanapaphawong, P. Reubroycharoen, and A. Yamaguchi, “Conversion of cellulose into lactic acid catalyzed by zirconium oxide catalysts,” *RSC Advances*, vol. 7, no. 30, pp. 18561–18568, 2017.

[362] P. Wattanapaphawong, O. Sato, K. Sato, N. Mimura, P. Reubroycharoen, and A. Yamaguchi, “Conversion of cellulose to lactic acid by using ZrO2-Al2O3 catalysts,” *Catalysts*, vol. 7, no. 7, p. 221, 2017.
