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Advances in Biofeedstocks and Biofuels

PRODUCTION TECHNOLOGIES FOR BIOFUELS

Edited by
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Processing of Bioethanol from Lignocellulosic Biomass

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Abstract

Increasing population and urbanisation combined with depleting fossil fuel reserves have resulted in the need for the development of an alternative transport fuel source. Additionally, climate change associated with fossil fuels has resulted in the need for a greener energy source. Biofuels are fuels that are derived from biological sources to be used alone as transport fuel or as part of a fuel blend. Biofuels may provide a solution to the current fuel crisis and their need and potential is well-recognised. Bioethanol is a biofuel produced via the fermentation of sugars. Second generation bioethanol is produced from lignocellulosic biomass found in abundance in agricultural wastes. The complex structure of lignocellulose results in the necessity of a multi-step process encompassing: pretreatment, saccharification, fermentation, and distillation. Process integration is currently the most promising prospect in second-generation technologies, and efforts should now focus more on the optimisation of such integrated processes.

Keywords: Bioethanol, biofuel, lignocellulose, biomass, second generation, pretreatment, distillation, fermentation, saccharification, process integration

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1.1 Introduction

The demand for and consumption of energy has never been higher due to substantial increases in population and urbanisation. Mass increases in energy are required by transportation, industrial, and agricultural sectors; the use of fossil fuels has long played a primary role in providing for this need. However, in recent decades, it has been made apparent that this is a limited resource and reserves are incapable of sustaining the present rising demand. Major concerns are also raised regarding the environmental impact of the emissions of 'green house gases,' such as CO_2, when burning fossil fuels. These issues have given rise to a vital need to develop new greener sources of energy [1].

Biomass fuels (biofuels) are obtained from currently harvested biological sources and are not by any means a recent discovery. Burning plants for light and the use of solid biofuel for cooking was a common post 20th Century practice. More recently, the fuel crisis has seen an increased drive on the development of modern biofuels as an efficient, clean, and sustainable transport fuel alternative [2, 3]. Interest was renewed in the mid-1970s when production of ethanol from sugarcane and corn began in Brazil and the USA. Their need and potential has since been recognised and is supported by government policies, with over 50 countries setting biofuel blending targets and quotas [4, 5].

One of the most predominant biofuels presently being utilised and developed is bioethanol, C_2H_6O, which is structurally identical to ethanol (see Figure 1.1b). First

(1st) generation bioethanol is produced from the fermentation of edible sugars and starch sourced from crops grown primarily for the production of biofuels. Unfortunately, issues arise in the production of 1st generation bioethanol as the growth of crops for energy, as opposed to food, results in reduced food production and, consequently, increased food prices. Second (2nd) generation bioethanol offers a potential solution as it utilises non-edible lignocellulosic biomass found in abundance in readily available agricultural wastes such as corn stover, sugarcane bagasse, straw, and woodchips [2, 6]. Lignocellulosic biomass is principally composed of cellulose, hemicellulose, and lignin. The complex structure of lignocellulose results in the necessity of a multi-step process to produce bioethanol; an overview of the process is shown in Figure 1.1a and Figure 1.1b [7].

1.2 Method

1.2.1 Pretreatment

The structure of lignocellulose consists of polymers of cellulose and hemicellulose encased in lignin; ratios of these components may vary largely, depending on the source of the biomass. Pretreatment of the lignocellulosic biomass promotes the depolymerisation and removal of the lignin outer layer. This structural deformation results in the exposure of cellulose and hemicellulose, and an increase in biomass surface area which is essential for optimal hydrolysis [8].

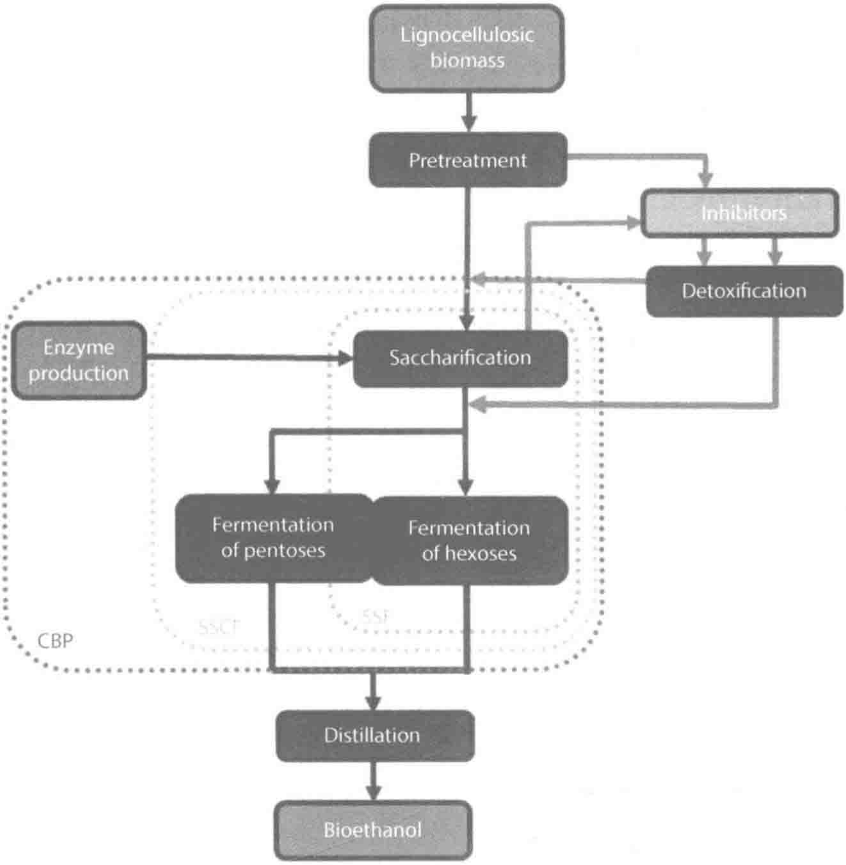

Figure 1.1a A process flow diagram depicting the key process steps required in the production of bioethanol from lignocellulosic biomass. SSF: Simultaneous saccharification and fermentation; SSCF: Simultaneous saccharification and co-fermentation; CBP: Consolidated bioprocessing.

Pretreatment methods range through physical, chemical, and biological (see Table 1.1); in some cases, a combination of methods may be employed to give optimum cellulose/hemicellulose exposure. The method of pretreatment exploited depends fundamentally on the biomass source. An optimum pretreatment method is characterised by the following criteria; minimum degradation of cellulose and hemicellulose fractions,

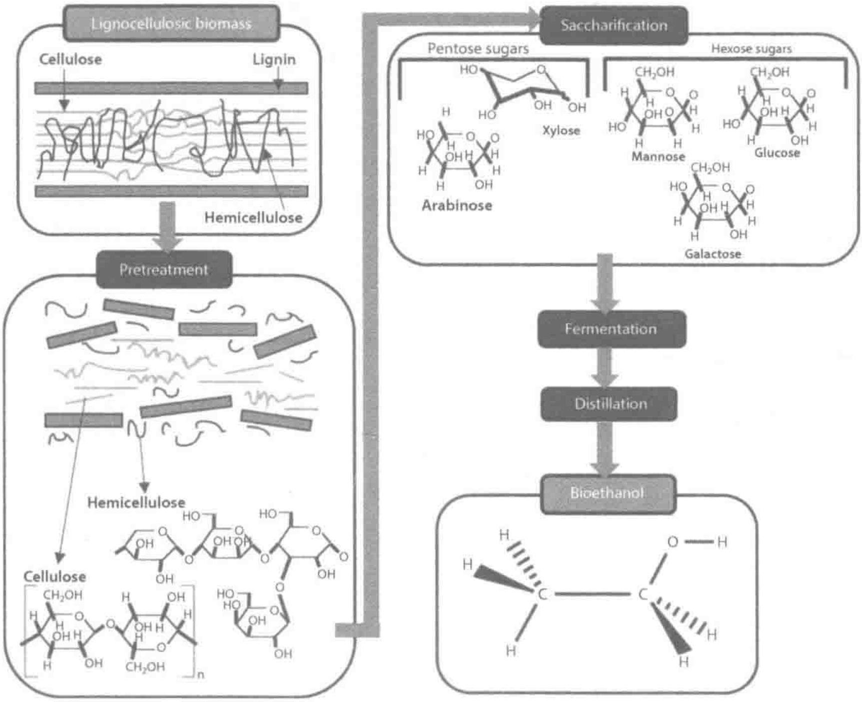

Figure 1.1b Overview of the key modifications and products attained at various stages of lignocellulosic biomass to bioethanol processing. Lignocellulosic biomass consists of cellulose and hemicellulose bound by lignin. Pretreatment of lignocellulose depolymerises the lignin exposing the cellulose and hemicellulose. Saccharification aims to hydrolyses cellulose and hemicellulose into their constituent sugar monomers; glucose, galactose, mannose, xylose, and arabinose. Fermentation of the sugars followed by distillation allows the formation and subsequent recovery of bioethanol. Adapted from [12, 30].

limitation of inhibitor formation, biomass size conservation, minimal energy input, and cost-efficiency. At present, there is no single pretreatment method which is thought to encompass all of these traits as each bears individual advantages and disadvantages including, but not limited to, those shown in Table 1.1. The initial pretreatment step may also influence the selection of other methods in the remaining process [8, 9].

Table 1.1 A selection of pretreatments suitable for lignocellulosic biomass [8, 9, 11, 12, 21, 35–37].

Pretreatment		**Method**	**Advantages**	**Disadvantages**
Physical	Mechanical (Milling)	Biomass particle size is physically reduced increasing accessible surface area	No inhibitors produced	High energy requirement High equipment cost
Chemical	Concentrated Acid	Concentrated biomass (10–40%) is submerged in concentrated acid at <160 °C	Simultaneously promotes cellulose and hemicellulose hydrolysis Minimal sugar degradation	Corrosion of equipment High inhibitor formation Slurry requires neutralisation Acid must be recovered
	Dilute Acid	Low concentration biomass (5–10%) is combined with a low concentration dilute acid at a ~220 °C	Low acid usage Cost efficient	Corrosion of materials Slurry requires neutralisation

	Alkali	Biomass is incubated with alkaline bases, such as sodium and potassium hydroxide resulting in the degradation of ester and glyosidic side chains	Does not require complex reactors Low inhibitor formation Removes hemicellulose making cellulose more accessible	Long residence time Slurry requires neutralisation Irrecoverable salts formed May cause chemical swelling of fibrous cellulose
	Ozonolysis	Ozone gas is utilised as powerful oxidant to break down bonds in lignin and hemicellulose	No toxic residues produced Reduces lignin content	Large volume of ozone required–high cost
Biological	White-, brown-, soft-rot fungi	Wood degrading microorganisms are added to the biomass and incubated at conditions suitable for the chosen microorganism	Environmentally sound Re-usable Particularly suitable for biomass with high lignin content	Long residence time Low yields of fermentable sugars

(Continued)