

Chapter 3

Conversion of Biomass to Fuel

Abstract The overview on conversion of biomass to fuel is presented in this chapter. The conversion includes the hydrolysis of various components in the lignocellulosic materials to fermentable reducing sugars and the fermentation of the sugars to fuels such as ethanol and butanol. The pretreatment step is mainly required for efficient hydrolysis of cellulose to its constituent sugars. The hydrolysis is usually catalyzed by acids or cellulase enzymes, and the fermentation is carried out by yeasts or bacteria. The factors affecting the hydrolysis of cellulose include porosity of the biomass materials, cellulose fiber crystallinity, and content of both lignin and hemicelluloses.

Keywords Biomass · Fuel · Reducing sugar · Fermentation · Ethanol · Butanol · Pretreatment · Hydrolysis · Cellulose · Enzymes · Porosity · Crystallinity · Lignin · Hemicelluloses

The history of ethanol as a fuel dates back to the early days of the automobile era. However, cheap petrol (gasoline) rapidly replaced ethanol as the fuel of choice, and it was during the late 1970s, when the Brazilian government launched their “Proalcool” Programme, that ethanol made a comeback to the market place. Today, fuel ethanol accounts for roughly two-thirds of world’s ethanol production (Saxena et al. 2009). Ethanol is a comparative cleaner burning fuel with high octane and fuel-extending properties. Although blending of ethanol with petrol enhances the volatility of the mixture, on the contrary, ethanol reduces the emission of carbon monoxide from vehicles. The use of petrol blended with 20–24 % ethanol is a standard practice in Brazil. Global ethanol production is shown in Table 3.1. Growth in world ethanol production crucially depends on the development of the fuel alcohol market. Spurred on by the Brazilian “Proalcool” Programme and the US Gasohol scheme, output jumped in the early 1980s, and growth continued at very strong rates up to the mid-1990s. In 1998, fuel alcohol production fell sharply due to the crisis in the Brazilian alcohol sector, which was not compensated by the record output in the United States. Requirement of ethanol in the first phase of the programs on 5 % blending in petrol in India, was 3.45 billion liters a year, which

Table 3.1 World fuel ethanol production by country or region (million gallons) in 2014

United States	14,300
Brazil	6190
Europe	1445
China	635
Canada	510
Thailand	310
Argentina	160
India	155
Rest of World	865

could have gone up to 5.00 billion liters had the program been introduced throughout the country (Saxena et al. 2009). Several government laboratories, academic institutions, and private sector companies have developed several techniques to accomplish each of the steps required to process the biomass to ethanol. There are different technological options available for the techno-economically feasible process for ethanol production from biomass. Currently, the production of ethanol by fermentation of corn-derived carbohydrates is the major technology used to produce liquid fuels from biomass resources. Dilute acid can open up the biomass structure for subsequent processing. The simultaneous saccharification and fermentation (SSF) process are favored for producing ethanol from the major fraction of lignocellulosic biomass, cellulose, because of its low cost potential.

Figure 3.1 shows a schematic for the conversion of biomass to fuel. The conversion includes the hydrolysis of various components in the lignocellulosic materials to reducing sugars and the fermentation of the reducing sugars to fuels such as ethanol and butanol. The pretreatment step is mainly required for efficient hydrolysis of cellulose to its constituent sugars. The hydrolysis is usually catalyzed by acids or cellulase enzymes, and the fermentation is carried out by yeasts or bacteria. The factors affecting the hydrolysis of cellulose include the following (McMillan 1994):

- Porosity (accessible surface area) of the biomass materials
- Cellulose fiber crystallinity
- Lignin and hemicellulose.

The presence of lignin and hemicellulose makes the accessibility of cellulase enzymes and acids to cellulose more difficult, thus reducing the efficiency of the hydrolysis process. Pretreatment is required to change the size and structure of the biomass and also its chemical composition, so that the hydrolysis of the carbohydrate fraction to monomeric sugars can be obtained rapidly and with greater yields. The hydrolysis process can be improved substantially by removal of lignin and hemicellulose, increase of porosity, and reduction of cellulose crystallinity through pretreatment processes (McMillan 1994). In the hydrolysis process, the sugars are released by breaking down the carbohydrate chains, before they are fermented for alcohol production. The cellulose hydrolysis processes include acid hydrolysis and

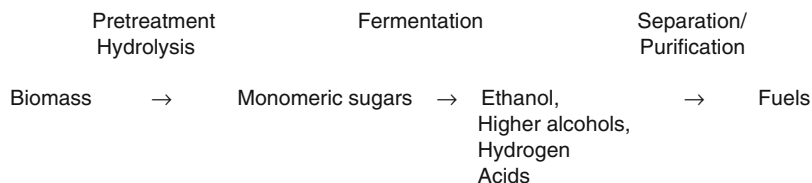


Fig. 3.1 Schematic of the conversion of lignocellulosic biomass to biofuels

an enzymatic hydrolysis. In traditional methods, hydrolysis is performed by reacting the cellulose with an acid. Dilute acid can be used under conditions of both high temperature and pressure whereas concentrated acid can be used at lower temperatures and atmospheric pressure. The decrystallized cellulosic mixture of acid and sugars reacts in the presence of water to liberate individual sugar molecules. The dilute acid process is actually a harsh process that leads to the formation of toxic degradation products that can interfere with fermentation. Cellulose chains can also be broken down into individual glucose sugar molecules by cellulase enzymes. Cellulase refers to a class of enzymes that catalyze the hydrolysis of cellulose. These enzymes are produced mainly by fungi, bacteria, and protozoans. Some cellulases are also produced by plants and animals. The reaction occurs at body temperature in the stomachs of ruminants such as cows and sheep, where the enzymes are produced by intestinal bacteria. Lignocellulosic materials can similarly be enzymatically hydrolyzed under relatively mild conditions. This enables effective cellulose breakdown without the formation of byproducts that would otherwise inhibit enzyme activity. The six-carbon sugars are readily fermented to ethanol by several naturally occurring organisms (Mosier et al. 2005). Traditionally, baker's yeast has been used in the brewing industry to produce ethanol from six-carbon sugars. Due to the complex nature of the carbohydrates present in lignocellulosic biomasses, five-carbon sugars derived from the hemicellulose portion of the lignocellulose are also present in the hydrolysate. For example, the hydrolysate of corn stover contains approximately 30 % of the total fermentable sugars as xylose. As a result, the ability of the fermenting microorganisms to use the whole range of sugars available from the hydrolysate is very much important for increasing the economic competitiveness of cellulosic ethanol and potentially bio-based chemicals. The metabolic engineering of microorganisms used in fuel ethanol production has shown significant progress (Jeffries et al. 2004). For cellulosic ethanol production, several microorganisms such as *Zymomonas mobilis* and *Escherichia coli*, in addition to *Saccharomyces cerevisiae*, have been targeted through metabolic engineering. Several engineered yeasts have been found to efficiently ferment xylose and arabinose and also mixtures of xylose and arabinose (Ohgren et al. 2006; Becker and Boles 2003; Karhumaa et al. 2006). The recovery of fuels from the fermentation broth is obtained by distillation or using a combination of distillation and adsorption. The other components including residual lignin, unreacted cellulose and hemicellulose, and enzymes, accumulate at the bottom of the distillation column.

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