Journal of Environmental Chemical Engineering 2 (2014) 573–584

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

journal homepage: www.elsevier.com/locate/jece

Review

Bioethanol production: Feedstock and current technologies

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ARTICLE INFO

Article history:
Received 11 April 2013
Received in revised form 11 October 2013
Accepted 22 October 2013

Keywords:
Ethanol
Lignocellulosic waste
Sugarcane
Starch
Syngas

ABSTRACT

Fossil fuels such as oil, coal and natural gases have become the prime sources of energy in the current era. However, it is anticipated that these sources will deplete within the next 40–50 years. The expected environmental damages like global warming, acid rain and urban smog have tempted us to reduce the carbon emissions by 80% (v/v) and shift toward utilizing a variety of renewable energy resources such as solar, wind, biofuel, etc. that are less environmentally harmful in a sustainable way. Ethanol is one of the most promising alternative biofuel. Although the energy equivalent of ethanol is 68% lower than that of petroleum fuel, the combustion of ethanol is cleaner (because it contains oxygen) and thus it recognize as a potential biofuel alternative to gasoline. Ethanol has been frequently used for the blended gasoline in the concentration range 10–85% (v/v). More recently, ethanol is identified as a fuel for the direct ethanol fuel cells (DEFC) and biofuel cells. Sugarcane and corn feedstock, are the main source of ethanol. Nevertheless, it is barely sufficient to meet the current demand. Lignocellulosic biomass is an alternative source but its availability is poorly documented. This review discusses the current status of ethanol production from different feedstocks and the state of technologies involved in ethanol production from such different feedstock.

Contents

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http://dx.doi.org/10.1016/j.jece.2013.10.013

Introduction

Ethanol (CH_3CH_2OH) is the most popular alcoholic biofuel available in the current world market. Henry Ford has used the term "fuel of the future" for the ethanol. There are several reasons for being its use as alternative fuel such as (i) it is produced from the renewable agricultural products like corn, sugar, molasses including other products rather than nonrenewable petroleum products, (ii) it is less toxic than other alcoholic fuels, and (iii) by-products of incomplete oxidation of ethanol (e.g. acetic acid and acetaldehyde) are less toxic than the by-products formed from other fuel alcohols [1].

The world total ethanol production during 2009–2010 was almost 100 billion liters. The world ethanol consumption was 68% for fuel, 21% for industrial and 11% for potable purpose [2]. It is used to partially replace gasoline to make gasoline-ethanol mixtures, E15 (15% ethanol and 85% gasoline) and E85 (85% ethanol and 15% gasoline). Bioethanol is a liquid biofuel which can be produced from several different biomass feedstocks and conversion technologies. The feedstock used for fuel ethanol production is mainly sugarcane in tropical areas such as India, Brazil and Colombia, while it is dominantly corn in other areas such as the United States, European Union, and China [3]. Ethanol production from sugar crops such as sugarcane and sugar beet account for about 40% of the total bioethanol produced and nearly 60% corresponding to starch crops [4]. Due to increasing demand for ethanol in the last few years and due to shortage of molasses and corn, the prices of ethanol are increasing day by day. Also due to its increase in demand as a food source and its rising price, the availability and feasibility of using corn as a feedstock is in stake. The further expansion of ethanol production from many of these feedstock's, thus triggers debate on food/feed versus fuel, limiting the use of first generation feed stock for ethanol production. Thus for sustainable fuel grade ethanol production, non-food feedstock should be used. There is an urgent need for development of second generation bioethanol [5].

Second-generation fuels are generally those made from non-edible lignocellulosic (LC) biomass, either residues of forest management or food crop production (e.g. corn stalks or rice husks) or whole plant biomass (e.g. grasses or trees grown specifically for biofuel purposes). LC biomass, also called cellulosic biomass, is a complex composite material consisting primarily of cellulose, hemicellulose and lignin bonded to each other in the plant cell wall. This Lignocellulosic biomass such as agri-residues (e.g., corn stover, wheat and barley straws), agri-processing byproducts (e.g., corn fiber, sugarcane bagasse, seed cake, etc.), woody biomass (hardwood and softwood) and energy crops (e.g., switch grass, poplar, banagrass, miscanthus, etc.) do not compete with food and feed, and are considered to be renewable feedstocks for ethanol production [6].

This review examines what is currently known regarding different feedstock's and technologies that are used in bioethanol production with respect to its overall conversion technology. This review also provides a brief summary of the current challenges and barriers that interfere with each substrate based-ethanol pathway and places the emphasis on potential issues challenging biotechnological conversion and performance of the bioethanol production process.

Overall process of bioethanol production

The process of ethanol production depends on the raw materials used. Ethanol production commonly carried out into the major three steps: (1) to obtain the solution containing fermentable sugars, (2) conversion of sugars into ethanol by fermentation and (3) ethanol separation and purification, usually by distillation–rectification–dehydration. The fermentation process can use any sugar-containing material to produce ethanol (Fig. 1) [7].

Based on Fig. 1, one or more steps can be combined depending on the feedstock and the conversion technology. Once the biomass reaches the ethanol plant, it is stored in a warehouse where it is conditioned to prevent early fermentation and bacterial contamination. Through the pretreatment, carbohydrates are extracted or made more accessible to the further extraction. During this step, the amounts of available sugars depend on biomass and pretreatment used. A large portion of fibers may remain for conversion into simple sugars through hydrolysis reactions or other techniques. The hydrolysate, yeasts, nutrients and other ingredients are added to the fermentation at the beginning of the batch operation. In a fed batch process, one or more inputs are added as fermentation progresses. Continuous processes in which ingredients are constantly input and products removed from the fermentation vessels are also used. In efficient processes, the cell densities may be made high by recycling or immobilizing the yeasts in order to improve their activity and increase the fermentation productivity [8]. The fermentation reactions occurs at temperatures between 25 °C and 30 °C and it last between 6 h and 72 h depending on the composition of the hydrolysate, cell density, physiological activity and yeast species. The broth typically contains 8–14% of ethanol on a volume basis. Above this latter concentration, inhibition of yeasts may occur that reduces their activity. The distillation step yields an azeotropic mixture made up of 95.5% alcohol and 4.5% water that is the "hydrous" or "hydrated" ethanol which is then dehydrated to obtain an "anhydrous" ethanol containing up to 99.6% alcohol and 0.4% water. The remaining flow from the distillation column, known as vinasse, or stillage can be volatilized to produce co-products,

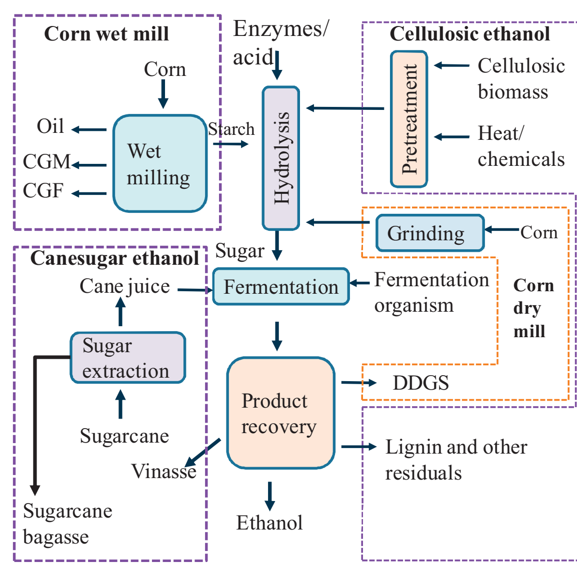

Fig. 1. Schematic representation of production of ethanol from cane sugar, corn, and cellulosic biomass. All have similar fermentation and ethanol recovery operations but use different approaches to release sugars and generate differentcoproducts. Sugar can be directly extracted from sugarcane, and the residual bagasse is used as a boiler fuel to provide much of the energy for the extraction and ethanol production and recovery operations. In a corn dry mill, corn is ground, and enzymes and heat are added to hydrolyze starch to sugars for conversion to ethanol, while the oil, protein, and fiber in corn are recovered after fermentation as an animal feed known as DDGS. Wet mills first fractionate corn to separate corn oil, corn gluten meal (CGM), and corn gluten feed (CGF) to capture value for food and animal feed, and the starch can then be hydrolyzed to sugars for fermentation to ethanol. For cellulosic biomass, heat and acids or enzymes hydrolyze the hemicellulose and cellulose portions to release sugars that can be fermented to ethanol, and the lignin and other remaining fractions can be burned to provide all the process heat and electricity for the conversion step with excess electricity left to export [8].