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Review

Consolidated briefing of biochemical ethanol production from lignocellulosic biomass

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ABSTRACT

Bioethanol production is one pathway for crude oil reduction and environmental compliance. Bioethanol can be used as fuel with significant characteristics like high octane number, low cetane number and high heat of vaporization. Its main drawbacks are the corrosiveness, low flame luminosity, lower vapor pressure, miscibility with water, and toxicity to ecosystems. One crucial problem with bioethanol fuel is the availability of raw materials. The supply of feedstocks for bioethanol production can vary season to season and depends on geographic locations. Lignocellulosic biomass, such as forest-based woody materials, agricultural residues and municipal waste, is prominent feedstock for bioethanol cause of its high availability and low cost, even though the commercial production has still not been established. In addition, the supply and the attentive use of microbes render the bioethanol production process highly peculiar. Many conversion technologies and techniques for biomass-based ethanol production are under development and expected to be demonstrated. In this work a technological analysis of the biochemical method that can be used to produce bioethanol is carried out and a review of current trends and issues is conducted.

Contents

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1. Introduction

Nowadays, the depletion of fossil fuels and the environmental compliance regarding the greenhouse gases has attracted the interest in non-conventional fuel from bioresources [1,2,3,4,5]. For the past few years, the biomass-based ethanol has caught the attention of global industry. According to the Renewable Fuels Association [6], United States (U.S.) and Brazil are the pioneer countries in global bioethanol production with a percentage of approximately 90%. The involvement of several countries has already begun in new pathway development for biogasoline from biomass [7]. Wheals et al. [8] refer that in North America, bioethanol is primarily provided from starch sources (corn starch) while in South America is mostly extracted from sugars (sugarcane juice) and molasses [8,9]. (See Tables 1–3.)

On the other side, the European countries focus on biodiesel and biogasoline production which exceeds 50% of the global production cause of engines development and feedstocks supply costs [10,11,12, 13,14]. Despite the fact that most of the countries in the world, China, India and Japan continue to invest in technologies from agricultural residues and appear as future producers [15,16,17,18,19]. Although bioethanol based on corn and sugar is an encouraging replacement to gasoline in transportation sector, the amount produced is insufficient with respect to the annual consuming amount worldwide. There is no black-and-white answer to the question of what constitutes the most suitable feedstock for the bio-based economy. Generally, sugars, oils and proteins can be used in many applications. The concern for the food security has globally increased the interest of researchers to focus on alternative feedstocks [20,21,22].

The nova Institute of Germany claims that lignocellulosic resources are favorable in terms of environmental sustainability and food security as they do not antagonize food crops and animal feed as renewable substrate for bioethanol production [23,24]. Moreover, the availability of lignocellulosic materials in industrial-scale basis is increased cause of the exploitation of industrial wastes and agricultural residues [25,26,27]. Lignocellulosic wastes are a promising feedstock considering its availability and low cost. The utilization of corn stover, rice, wheat and sugarcane bagasse is gaining significant importance worldwide [28,29,30,31].

Nonetheless, the recalcitrant structure of lignocellulose requires high capital cost processing. Therefore, these technologies are not economically achievable [32,33]. During the decomposition of lignocellulosic material, it must be considered that D-xylose is the second important sugar which has to be broken down as is found in high portion in the feedstock [34]. The conversion of biomass to ethanol has 4 main steps: pretreatment, hydrolysis, fermentation and distillation. During the last decades genetic engineering and enzymatic processing have provided significant improvements in all of the four steps of ethanol production and making capable to ferment different sugars concurrently [35,36,37]. Even though there is a wide range of bacteria, they cannot all be adapted to saccharification process conditions and several bacteria produce low ethanol yields. For this reason, subtle improvements are sometimes required [38].

The microbial contamination is a crucial problem in bioethanol production process. Bacterial infections occur during bioethanol fermentation which consume nutrients necessary for the fermentation itself and it is possible to produce toxic products too. Both of these situations can negatively affect the bioethanol yield [39,40]. The formation of inhibitory by-products during the biofuel production must be taken into account. Pienkos and Zhang [41] refer that pretreatment and conditioning processes release toxic compounds into the hydrolysate which inhibit the bacteria growth and decrease the ethanol yield. The mechanism/methodology applied for biomass pretreatment influences the relevant toxicity rate [41,42]. This review examines recent technologies and trends that are used in lignocellulosic bioethanol production. It also provides a summary of the current problems and barriers concerning the different pathways and analyses potential issues and trends of biotechnological conversion performance.

Table 1
Top five bioethanol producers (billion gallons) [45]

Country	2008	2010	2012	2014
US	9.31	13.30	13.22	14.34
Brazil	6.47	5.57	5.57	6.19
Europe	0.73	1.21	1.14	1.45
China	0.50	0.54	0.56	0.64
Canada	0.24	0.36	0.45	0.51

2. Current status

In 2014, the global production of bioethanol reached 24.5 billion gal, up from 23.4 billion gal in 2013 which shows the international bioethanol market is at a very dynamic stage [43]. More than half (about 60%) of global bioethanol production is based on sugar cane conversion and the rest (40%) comes from other crops [44]. United States and Brazil are the global producers as they produce more than 70% of the global bioethanol production.

Even the main source for bioethanol production is considered to be the corn from US and sugar cane from Brazil, any country with agro-industrial economy can be involved in bioethanol fermentation. This is feasible cause of the current progress in bioconversion of non-food crops in large scale production [46].

In Europe the biochemical pathways show a crucial potential for research development in conjunction with the progress in biorefineries. It is important to clarify that several technologies are under development such as the SSCF technology which gains space in biotechnology research area. Research requires effort to solve problems concerning process improvement and confront challenges regarding the overall efficiency of a biorefinery [47]. It was also reported in 2009 that notwithstanding the global economic-constraints, bioethanol production continues to increase and to support significantly to the global development [48].

3. Lignocellulosic sources and composition

3.1. Raw materials and characteristics

Sustainable biofuel production in Europe can be met with lignocellulosic biomass usage [49]. There is a wide variety of raw materials that are discerned by their makeup, structure and process-ability. In North America most cultivated land comprises.

The land cultivation is mainly based on forestland (around 35%), grazed land (27%) as well as crop lands (19%) which constitute approximately 9.0 million km^2 [51,52,53]. Forest sources include woody biomass consisting mainly of residues or by-products from manufacturing processes, biomass plantations, agricultural residues (trees and branches) [54,55]. Cellulose materials can also be collected

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