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Overview of technical barriers and implementation of cellulosic ethanol in the U.S.

Tae Hoon Kim [a], Tae Hyun Kim [b, *]

[a] Department of Applied Chemical Engineering, Dankook University, Cheonan, Chungnam 330-714, Republic of Korea
[b] Department of Environmental Engineering, Kongju National University, 1223-24 Cheonandae-Ro, Budae-dong, Cheonan, Chungnam 330-717, Republic of Korea

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ABSTRACT

There is mounting concern about the buildup of carbon dioxide (CO_2) and other so-called greenhouse gases in the atmosphere. In general, bioethanol production requires minimal fossil fuel input in the conversion step, and ethanol is considered a promising alternative fuel to petroleum-derived products. It is anticipated that ethanol production with second-generation biomass, i.e. lignocellulosic materials, will be possible on a large scale in the near future. Latest efforts have been focused on overcoming technical challenges in bioconversion, particularly pretreatment, and finding the solutions required to implement biorefinery on a large scale. This paper introduces and reviews the current status of research, and of the ethanol industry in the U.S. In addition, other important concepts in biofuels, cellulosic ethanol, and biorefinery in general are reviewed, and the key technical issues in bioconversion of cellulosic ethanol, such as pretreatment and factors affecting bioconversion of biomass are also discussed.

1. Introduction

The economy of the United States is the world's largest national economy. Its nominal GDP was estimated to be over $15.7 trillion in 2012 [1]. The U.S.'s present economy is mostly dependent on fossil energy sources including oil, coal, natural gas, and so on. The United States was ranked second in the world after China in terms of CO_2 emitted as of 2011; China and the U.S. emitted 23.3% and 18.2% of the global total, respectively [2]. The amount of CO_2 released has resulted in growing pressure by the international community for the U.S. to join the mandatory reduction programs. Under the Kyoto Protocol of 1997, which is a working agreement of the UNFCCC (United Nations Framework Convention on Climate Change), Annex I countries must reduce their aggregate emissions of greenhouse gases by at least five percent from 1990 levels during the 2008–2012 period.

It is also anticipated that the future energy system in the US will be more dependent on the various alternative energy technologies including solar, wind, tidal, geothermal, fuel cells, and biofuels from biomass. In particular, according to the U.S. EISA (Energy Independence and Security Act), the consumption of biofuels, such as biomass-based diesel and advanced biofuels, will increase one hundred-fold during the next 10 years [3].

A biorefinery is a new concept in which fuels, power, and chemicals can be produced from biomass in the same way that today's petroleum refineries produce multiple fuels and products from petroleum. Biorefinery technologies have been generally identified as the most promising route to the creation of a new domestic bio-based industry, to the development of a sustainable industrial society, to energy independence, and to the effective management of greenhouse gas emissions [4–7].

There is no doubt that renewable energy will be the most important product of the future bio-based economy. Among various alternative or renewable energies, ethanol production from renewable resources is now being accepted across the world as a visible substitute for traditional petroleum based fuels. In particular, cellulosic ethanol, in other words bioethanol, can be produced from inexpensive and abundant lignocellulosic biomass. This lignocellulosic biomass is the most available potential feedstock for the production of bioethanol, which is currently the most widely used liquid biofuel alternative to fossil fuels [8].

Use of bioethanol has many advantages in terms of the environment, national energy security, and rural economic improvement. Currently, a lot of research and work towards commercialization are being done to meet rapidly growing energy demands. Ethanol is

* Corresponding author. Tel.: +82 41 521 9426; fax: +82 41 552 0380.
E-mail addresses: hitaehyun@gmail.com, thkim@kongju.ac.kr (T.H. Kim).

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presently being promoted as a promising alternative fuel for transportation; the use of fossil fuels has contributed to the buildup of carbon dioxide in the atmosphere, however ethanol is a clean-burning fuel that makes a significantly lower contribution to global warming than any other fossil fuels because the carbon dioxide produced by the combustion of ethanol is consumed by plant growth, thus maintaining the natural carbon cycle balance.

This paper introduces and reviews the current status of research, of technical barriers in bioconversion, and of the ethanol industry in the U.S., which is one of the leading countries in biorefinery, specifically ethanol research and industry, and has vast cropland available for the planting of biomass, as well as abundant biomass resources.

2. Feedstock and present ethanol industry

In general, biomass can be divided into first generation crops such as sugars from sugar cane or sugar beets, and starch from corn, rice, wheat, and so on, and second generation energy sources such as various lignocelluloses and algae including macro- and micro-algae (Fig. 1). Corn grain is the primary feedstock used for the production of fuel ethanol in the United States, producing about 13.3 billion gallons of corn ethanol in 2012 [9]. Therefore, ethanol production is concentrated in the Midwest corn-belt states. Meanwhile, the RFA (Renewable Fuel Association) reported that there were only 50 ethanol plants in 2000, a number which had increased to 198 by 2011 (Fig. 2). Fig. 2 also indicates that 76 plants were under construction in 2005, while this number dropped sharply to seven in 2011. It collectively suggests that the ethanol demand in the US appears to be the saturation point and government' corn-starch ethanol mandates are only three years or 12% away from reaching their maximum [10].

Various cellulosic biomass resources are widely distributed across the United States. The NREL (National Renewable Energy Laboratory) provided information on the biomass resources available in the United States, which include agricultural residues, wood residues, and dedicated energy crops. According to the biomass resource distribution map, less biomass resources are available in the West, while greater inventories are available in the Mid-west, East, and South [11].

According to other reports, there are about 120 million dry tons of cellulosic biomass, mainly corn stover, corn fiber, wheat, rye, and barley straw, that can be sustainably harvested today, and which is enough to produce about five billion gallons of ethanol, roughly equal to half what the U.S. is making today from corn starch. On the other hand, more than one billion tons of biomass could potentially be harvested if dedicated energy crops could be developed, grown, and harvested sustainably. If this, along with sustainable harvesting of forestry and paper mill wastes were achieved, the U.S. could supply about 60 billion gallons of fuel ethanol; 30% of U.S. liquid transportation fuel needs [12–15].

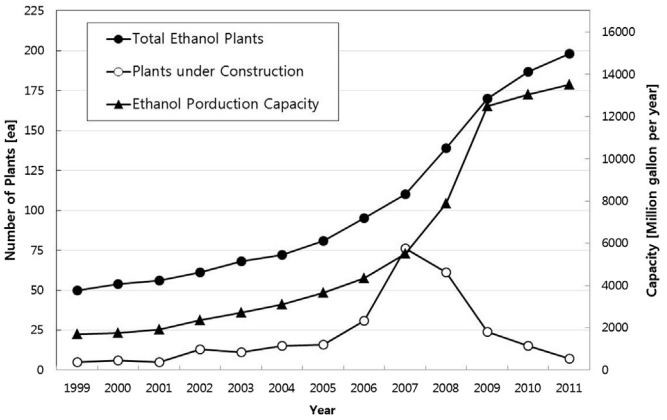

Fig. 2. Corn ethanol industry overview in the U.S. Source: Renewable Fuel Association http://www.ethanolrfa.org/ [9].

Achieving the cellulosic biofuel targets set forth in the Energy Independence and Security Act (EISA) of 2007 will require a very large increase in harvested cellulosic biomass feedstocks from agricultural, forest, and other resources. It is estimated that by 2022, nearly 180 million dry tons of biomass will be needed annually to produce the 16 billion gallons of cellulosic biofuels called for by EISA [16].

3. Advanced biofuels

Biofuels including bioethanol were typically categorized into first, second, and third generation biofuels. First generation biofuel is made from oil, sugars and starch, which can easily be converted to diesel, ethanol, and butanol using conventional technology.

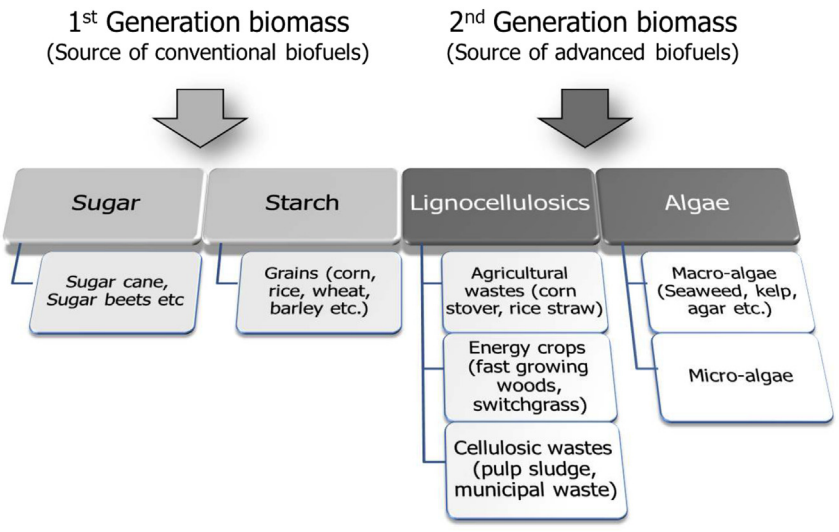

Fig. 1. Various biomass and classification.

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