Renewable and Sustainable Energy Reviews 37 (2014) 21–35

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Lignocellulosic biobutanol production: Gridlocks and potential remedies

Amruta Morone, R.A. Pandey*

Environmental Biotechnology Division, CSIR-National Environmental Engineering Research Institute (NEERI), Nagpur 440020, India

ARTICLE INFO

Article history:
Received 21 March 2013
Received in revised form
11 April 2014
Accepted 3 May 2014

Keywords:
Biobutanol
Lignocelluloses
Pretreatment
Enzymatic hydrolysis
Butanol tolerance
Process intensification

ABSTRACT

A spike in greenhouse gas emissions due to burning of fossil fuels and issues over energy security and its cost have obligated to identify the alternatives to petroleum fuels currently reigning transportation sector. Butanol, one of the substitutes, is still produced via petrochemical means but the confluence of global issues like declining oil reserves and upsurge in oil prices has compelled to identify renewable biomass resources for butanol production and commercialize the process. Biobutanol is one of the second-generation biofuels, superior to bioethanol, due to higher energy content, lower Reid vapor pressure, easy blending with gasoline at any ratio and ease in transportation. Although bioethanol, a strong competitor of biobutanol, has acquired enough attention from the transportation industry as the current commercially available liquid fuel for transportation, biobutanol possesses the potential to leapfrog various barriers and emerge as an attractive alternative biofuel. Lignocellulosic butanol production faces challenges in various frontiers such as cost of raw material, pretreatment strategies, enzymatic hydrolysis, and low butanol tolerance of the fermenting strain leading to its low yield and productivity, downstream processing of butanol, production of undesired solvents and the production cost. This review discusses these gridlocks along with the possible pertinent solutions to deal with these problems. It also sheds light on recent advancements coupled with the newer approaches for butanol production that revitalize the hopes on having a cleaner, energy-efficient commercial process.

Contents

Abbreviations: LCB, lignocellulosic biomass; LC, lignocelluloses; AFEX, ammonia fiber explosion; WAO, wet air oxidation; GHG, greenhouse gases; ABE, acetone–ethanol–butanol

* Corresponding author. Tel.: +91 712 2240097; fax: +91 712 2249900.
E-mail address: ra_pandey@neeri.res.in (R.A. Pandey).

http://dx.doi.org/10.1016/j.rser.2014.05.009
1364-0321/

1. Introduction

The worldwide energy consumption is increasing and on the other hand, fossil fuels are limited and it is dubious as to how long they will suffice the needs of humankind. The escalating fossil fuel and oil prices and climate change due to greenhouse gases have increased the quest for an alternative fuel that would be economical [1]. Biofuels, which can be produced either chemically or biotechnologically from renewable biomass, are CO_2 neutral and sound to be a promising alternative.

First generation fuels like ethanol, biodiesel and renewable diesel, made from sugars, grains and seeds, are produced commercially in many countries but have led to food vs. fuel war. On the other hand, second generation biofuels, made from non-edible parts of lignocellulosic biomass (hereafter referred to as LCB), are still on the path of commercialization [2]. It is anticipated that these second-generation biofuels will yield better energy, economics and carbon performance than first generation biofuels and are expected to overcome the limitations of first generation biofuels [3].

1-Butanol or n-butanol is a straight chain isomer ending in alcohol functional group. It is considered as superior biofuel as compared to ethanol due to easy blending with gasoline or diesel at any ratio, low octane values, lower energy density, lower Reid vapor pressure, biodegradability and ease in transportation [4–6]. Moreover, LC butanol is favorable from greenhouse gas (GHG) perspective as literature reports indicate 32–48% reduction in GHG due to LC biobutanol as compared to conventional gasoline [7]. Cobalt technologies, a key player in butanol production, claim that Cobalt's process reduces life cycle GHG emissions by 70–90% compared to gasoline [123]. These advantages prove biobutanol as a surrogate for bioethanol, thus, allowing it to take up the mantle.

LC-biobutanol production process involves pretreatment and hydrolysis of raw material followed by fermentation of sugars to butanol. LC-biobutanol is challenging in terms of conversion of lignocellulose to sugars and cost of bioconversion and hence research on commercializing biobutanol still lags behind as compared to that of bioethanol. The principal obstacle is high production cost which includes the capital investment and cost of equipment, raw materials, pretreatment, enzyme, strain development, recovery along with the cost for R&D and sales and marketing of butanol. The process can be made cost-effective by minimizing substrate cost, choosing an efficient pretreatment and hydrolysis method, use of engineered overproducing and butanol tolerant strains for fermentation and simultaneous recovery of butanol. Thus, realization and commercialization of biobutanol from LCB would require technological advancements in the fields of biotechnology and chemical engineering.

Reviews on butanol have been cited in literature reports covering pretreatment, hydrolysis and fermentation separately [8–13]. However, there is scanty information available by integrating all the stages of butanol production together. The novel aspect of the present review is that it covers all the stages of butanol production viz. raw materials, pretreatment, hydrolysis, fermentation, recovery and integration of all the unit operations reflecting the existing status, gridlocks involved at each stage and their remedies. Further, this review also discusses the cost contributing factors and analyzes the R&D strategies and the latest technologies to make the process practical and cost-effective.

Table 1
Substrates used for butanol production.

Sr.№	Substrate	Reference
1	Corn stover	[28]
2	Apple pomace	[29]
3	Cane molasses	[30]
4	Rice, wheat, corn, millet, rye and tapioca	[30]
5	Soy molasses	[31]
6	Corn meal	[32]
7	Wheat straw hydrolysate	[33]
8	Corn fiber hydrolysate	[34]
9	Distillers' dry grain solubles	[35]
10	Barley straw hydrolysate	[36]
11	Corn stover and switchgrass hydrolysate	[37]
12	Sweet sorghum bagasse	[38]
13	Jerusalem artichoke	[39]

2. Raw materials

LCB such as agricultural, forestry, agro-industrial and municipal solid wastes is now catching the eye of many researchers worldwide as an attractive alternative feedstock for butanol production owing to the several benefits it possesses such as high carbohydrate content (cellulose 35–50%, hemicelluloses 20–35%, lignin 10–25%), renewability, abundance, low cost and being carbon neutral [9]. Increased demand for biomass can generate employment in various sectors and provide incentive to improve rural transportation infrastructure, which would facilitate agricultural and economic development. Large scale production of biomass, if made profitable enough can attract farmers to take up the job, ensuring continual supply of biomass and good returns to the farmers, thereby, providing a boost to agribusiness and rural empowerment.

2.1. Bottlenecks

Although LCB is advantageous, several issues such as inconsistency in biomass availability, its composition, land and water requirements, cultivation practices, and logistics costs need to be addressed. These issues are the important factors that contribute to the overall process cost.

Studies by the Ministry of New & Renewable Energy, Government of India, suggest that the biomass availability is 120–150 million metric tons per year [14] including the agricultural and forestry residues. This includes LCB of diverse nature since the quality depends on the crop from which it is derived and its age [15]. Various raw materials used worldwide for butanol production are listed in Table 1. However, availability of a particular biomass may not be constant throughout the year. This poses a severe glitch for the biobutanol production industry.