International Journal of Chemical Studies 2019; 7(2): 2197-2200

International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(2): 2197-2200

Received: 06-01-2019
Accepted: 10-02-2019

Shruti Mohapatra
Sr Research Fellow, BPCL-OUAT Biofuel project & Ph.D. Scholar, Department of Agricultural Economics, OUAT, Bhubaneswar, Odisha, India

Raj Kishore Mishra
Professor and Head, Department of Agricultural Economics, OUAT, Bhubaneswar, Odisha, India

Khitish K Sarangi
Assistant professor, Department of Agricultural Economics, OUAT, Bhubaneswar, Odisha, India

Correspondence
Shruti Mohapatra
PhD Scholar, Department of Agricultural Economics, OUAT, Bhubaneswar, Odisha, India

Economic appraisal of bio ethanol production technologies

Shruti Mohapatra, Raj Kishore Mishra and Khitish K Sarangi

Abstract

Transformation of the renewable and abundant biomass resources into a cost competitive, high performance bio fuel can reduce people’s dependence on fossil fuel and enhance energy security. However, there is limited understanding of the potential of bio fuel resources, their production technologies, and economic potential. This review provides a broad overview on current status of bio ethanol production technologies in terms of their economic viability. These technologies include pre treatment of biomass, the use of cellulolytic enzymes for depolymerisation of carbohydrate polymers into fermentable constituents and the use of robust fermentative microorganisms for ethanol production. Among all the available technologies, dilute acid hydrolysis followed by enzymatic hydrolysis by less expensive and more efficient cellulases has been found more promising towards the potential economics and environmental impact.

Keywords: Bio ethanol, Production technologies, Cost Structure

Introduction

Current scenario has depicted that the importance of alternative energy source has become even more necessary not only due to the continuous depletion of limited fossil fuel stock but also for the safe and better environment, with an inevitable depletion of the world’s energy supply, there has been an increasing worldwide interest in alternative sources of energy (Lynd, 2004; Herrera, 2004; Lin and Tanaka, 2006, Dien*et al.*, 2006)[18, 12, 16, 5]. Keeping in view all the above said advantages, biomass based fuel development technologies should rapidly gain momentum and the barriers imposed earlier should be removed for successfully attempting the production of bio ethanol at the commercial level.

It is welcome to understand that the use of bio ethanol as a source of energy would be more than just complementing for solar, wind and other intermittent renewable energy sources in the long run (Lin and Tanaka, 2006) [16]. During the last two decades, advances in technology for ethanol production from biomass have been developed to the point that large-scale production will be a reality in next few years (Yu and Zhang, 2004) [26]. Ethanol production from biomass can be summarized briefly into following steps: depolymerisation of holocellulose polymer into monomeric fermentable substrate, fermentation of depolymerised substrates, and the distillation of the fermentation broth to obtain dehydrated ethanol.

The ethanol yields and processes economics along with the technical maturity and environmental benefits of using ethanol blend fuel are the key parameters that determine the feasibility of bio ethanol production (Nguyen and Saddler, 1991) [20]. The burning fossil fuel at the current rate is likely to create an environmental crisis globally. Use of fossil fuel generates carbon dioxide, methane and a significant quantity of nitrous oxide. Most of these harmful gases are formed due to incomplete combustion of fossil fuel; since ethanol contains 35% oxygen that may result in a more complete combustion of fuel and thus reduces tailpipe emissions.

Moreover, biomass energy can play an important role in reducing green house gas emissions. Ethanol production process only uses energy from renewable energy sources. Hence no net carbon dioxide is added to the atmosphere, making ethanol an environmentally beneficial energy source (Bull *et al.*, 1992; Kheshgi*et al.*, 2000) [3, 14]. Furthermore, fuel ethanol from lignocelluloses may also open new employment opportunities in rural areas, and thus make a positive socio-economic impact. Developing ethanol as fuel, beyond its current role as fuel oxygenates will require developing lignocellulosic biomass as a feedstock because of its abundantly available and low cost.

The world ethanol production in 2004 was estimated to be 40 giga litres (GL) (Berg, 2004; Kim and Dale, 2004). Brazil and the US are the world leaders, which together accounted for about 60% of the world ethanol production exploiting sugarcane and corn respectively. In India, lignocellulosic biomass (crop residues, forestry and fruit and vegetable waste and weeds) is available in plenty. Renewable fuels particularly ethanol should get more and more attention all over the world.

The important issue that we wish to address affirmatively here is that the bio ethanol production, without doubt, needs an economical approach to address the global fuel needs. Research efforts are needed to design and improve the process, which would produce sustainable and economically feasible transportation fuel. Improvement in process economics using new designed cellulases enzyme cocktail are important factors in establishing a cost effective technology, besides the low cost of feedstock (Mojovic*et al*., 2006; Gray*et al*., 2006) [7]. For the long haul, it is very important to understand bio ethanol production technologies in terms of their economic viability, environmental feasibility and empowering employment opportunities before implementing a fuel ethanol policy. The choice of the best technology for lignocellulose to bio ethanol conversion should be decided on the basis of overall economics (lowest cost), environmental (lowest pollutants) and energy (higher efficiencies) that is, comprehensive process development and optimization are still required to make the process economically viable.

In reality, environmental considerations, energy and tax policies will determine the extent of fuel ethanol utilization in the future (Keim and Venkatasubramanian, 1989) [13] and therefore the role of one and all is very crucial to identify the gravity of the situation associated with bio ethanol production and use of it as an alternative fuel.

Economics of ethanol production technologies

The bioconversion cost of biomass to liquid fuel should be lesser than present gasoline prices for being competitive and getting economic importance (Wayman and Parekh, 1990; Subramanian *et al*., 2005) [28, 21]. There are much of increasing efforts by researchers working towards improvisation in the efficiency of biomass conversion technologies but still huge scope is there to bring down the cost of biomass-to-ethanol conversion. Important parameters for low cost ethanol production are mostly cost of feedstock and cellulolytic enzymes. Around 40 per cent of the cost for ethanol production is contributed by cost of biomass feedstock (Hamelinck*et al*., 2005) [10]. Potential analysis of bio ethanol both for short run and long run in terms of performance, economic aspects and key technologies has been done recently by Hamelinck and Faaij (2006) [11]. In this analysis, the production cost of bio ethanol was found to be within the range of 16-22 / GJHHV (Euro/Giga Joules High Heating Value) at present and down to 13 / GJHHV in future (2030). Major parameter which influences the production cost of ethanol is feedstock cost at a rate of 2-3 /GJ fuel. Integrated approaches by use of cheap feedstock and potent cellulases through larger industrial facilities could make the process more economically viable (Sun and Cheng, 2002; Dien*et al*., 2006) [22, 5]. Keeping this point of view, bio ethanol is selected and depicted as the entity for ascertaining energy security in future fuel interests and global requirements. The selection of feedstock for production of ethanol is mainly based on its current availability and uses. For example, agricultural residues like barley, sorghum and wheat straw are not preferable for bio ethanol production due to their use as animal fodder but on the contrary, agroresidues like sugarcane bagasse, rice straw, rice bran, groundnut shell, corn stover, Brassica carniata stalks and soyabean stalks etc can be used directly because these sources are not preferably used as fodder for livestock. Some dedicated energy sources like damaged rice and sorghum grains, sunflower stalks and hulls (Sharma *et al*., 2000) [23], Eicchorniacrassipies (Nigam, 2003) [19], P. brava (Sanchez *et al*., 2004)[24], and Saccharum spontaneum (Gupta, 2006) [8] are found feasible sources for bioethanol production. Apart from these organic waste and municipal solid waste (MSW) containing significant amount of cellulose can also be eco friendly thereby can help in solving problem of solid waste storage and management.

In India, Department of Biotechnology (DBT), Govt. of India (GOI) has financed a nationwide research project towards the utilization of some particular weeds like Lantana camara, Prosopis juliflora and fruit or vegetable waste into ethanol conversion due to their vast abundance, low cost and rich in fermentable carbohydrates. A crucial factor for lessening the cost of bio ethanol production can be used for larger industrial facilities rather than smaller ones. An integrated approach approach (Process engineering, fermentation and enzyme and metabolic engineering) can be taken for economic improvement in bio ethanol production Ward and Singh (2002) [29].

When plant size increases, there will be fall in investment per unit output of product. Increase in size by tenfold is seen to reduce unit cost less than half and also reduce unit cost of capital and conversion cost (Wayman and Parekh, 1990; Henke *et al*., 2006) [28]. By increasing the plant size, the investment per unit output of product falls off, a ten-fold increase in size reducing the unit cost to less than one-half and thereby reducing unit capital cost charges and conversion cost reducing profitability (Wayman and Parekh, 1990) [28]. Energy integration of ethanol production to an already existing plant such as pulp and paper plant can be helpful in improving the economy of bio ethanol production. Aristidou and Penttila (2000) [2] reported that the total cost of ethanol will be dropped from more than \$1.0 per litre to ~ \$0.3-0.5 per litre, with a projected cost of less than \$0.25 per litre in the near future.

Wilke*et al*. (1981) [30] has used a SHF operation for biomass conversion to ethanol along with its cost analysis and found that it is possible for ethanol to compete with gasoline at the oil prices at \$20 to \$30 per barrel. Foody (1988) [6] has outlined, how the improvement in production of cost effective cellulases could bring down the price of bio ethanol from 25-55 cents to 10-28 cents per liter. Subsequently, Wright (1988) [31] and Hinman*et al*. (1992) reported the cost scenario basing upon economic evaluation of bio ethanol with respect to the SSF mode of operation and calculated the benefits of SSF process over SHF technology. Wooly*et al*. (1999) studied the further economic analysis of bio ethanol (\$ 0.78 per gallon) and suggested that projected cost can be as low as \$ 0.20 per liter by 2015 if enzymatic processing and biomass improvement targets are met.The projected cost of ethanol production from cellulosic biomass as per the earlier estimates (\$4.63/gallon in 1980) has been reduced by almost a factor of four (\$1.22/gallon) over the last 20 years (Wyman, 1999; Wyman, 2001).However, Kadam *et al*. (2000) estimated that use of two-stage dilute acid hydrolysis process can give rise to cost of ethanol production at \$ 1.20 per litre.

Table 1: Comparative analysis of all production process with respect to cost structure.

S. N	Production process	Production cost (Initial)	Production cost (Final)	Reference
1	Energy integration of ethanol production with other plants	\$1/lr	\$(0.3-0.5)/lr	Aristidou and Pentilla (2000) [2]
2	SHF	\$(20-30)/ barrel	-	Wilke*et al.* (1981) [30]
3	Production of cost effective cellulose production	25-55 cents/lr	10-28 cents/lr	Foody (1988) [6]
4	Enzymatic processing and biomass improvement targets if met	\$0.78/gallon	\$0.2/gallon	Wooly (1999)
5	02 stage dilute acid hydrolysis	\$1.2/lr	\$1.0/lr	Kadam *et al.* (2000)
6	Corn dry grind process technology	\$0.235/lr	\$0.365/lr	Kwaiakowski (2006)
7	SSF	\$0.56/lr	-	Wingren*et al.* (2003) [25]
8	Designer cellulases and SSCF	20 cents/lr	-	Alzate*et al.* 2005 [1]
9	Decreasing enzyme cost (<10 cents/gallon)	75 cents/gallon	-	Griffith (2005)[2]
10	Use of recombinant E.coli K011	48 cents/gallon	-	Von sievers*et al.* (1994) [27]
11	Cell recycle process Vaccum fermentation	82.3 cent/gallon 80.6 cent/gallon	- -	Cysewki and wilke (1976) [4]

Kwaiatkowski and Co-workers (2006) developed a model using Super Pro Designer R software for cost evaluation of ethanol production for 40 million gal/year ethanol producing facility using corn dry-grind process technology. They have collected data from ethanol producers, equipment manufacturers, technology suppliers and engineers working in the different industries. The cost of ethanol was found to be increased from US\$ 0.235/L to US\$ 0.365/L as the price of corn increased from US\$ 0.071 to US\$ 0.125 /kg. The maximum efficiency need to be achieved with respect to higher yield and more productivity in economic production of ethanol from biomass by the bioconversion of pentosans and hexosans from lignocellulosic biomass to ethanol, which is determined by the cost of sugar. The average biomass cost amounts to ~\$0.06 per kg of sugar, or a contribution to the feedstock costs for ethanol production of as low as \$0.10 per liter (Aristidou and Penttila, 2000) [2]. Wingren*et al.* (2003) [25] assessed the SHF and SSF economic using cellulase enzymes in both configurations with SSF being less expensive by about 10%; and estimated the ethanol production cost of 0.56 – 0.67 \$/L. Later, they have studied the effect of reduction in yeast and enzyme concentration in SSF process and concluded final ethanol production cost 4.80 SEK/L (2.34 US\$/gal).

National Renewable Energy Laboratory estimations have shown that employment of designer cellulases and SSCF (simultaneous saccharification and co-fermentation) process can make possible the production cost of ethanol 20 cents per litre in next 15 years from lignocelluloses biomass. However, in both the process, the use of cellulase makes the process cost effective (Alzate*et al*., 2005; Gray*et al*., 2006) [1, 7]. US Department of energy analyzed that making enzyme cost less than 10 cents per gallon of ethanol can give rise to reduction in ethanol production cost to 75 cents/ gallon (Griffith and Atlas, 2005) [9]. Apart from focusing the economics of cellulase production cost, several studies are being carried out to improve the ethanol production by improving acid hydrolysis process. Luong and Tseng (1984) [17] evaluated the techno economics of ethanol production under continuous culture using immobilized cells of Z. mobilis using plug-flow reactor and found that at least 4 cents/gallon of ethanol could be saved using immobilized cells rather than the conventional batch system thereby the fixed cost is reduced which will increase the profitability of ethanol production by fermentation. Von Sivers*et al*. (1994) [27] found the economic cost of ethanol production (48 cents/gallon) from detoxified willow hemicellulosic hydrolysate using recombinant E. coli K011.

Cysewki and Wilke (1976) [4] described cell recycle and vacuum fermentation processes for continuous ethanol production on a production capacity of 78,000 gal ethanol / day employing molasses as the fermentation substrate and estimated ethanol production cost 82.3 and 80.6 cent/gal, for the cell recycle and vacuum processes, respectively.

Conclusion

In spite of laboratory based bio ethanol success stories, the production of fuel ethanol at plant scale still remains a challenging issue. A positive solution to this issue could bring economic advantage not only for fuel and power industry, but also benefit the environmental rehabilitation and balance issues and cause.Worldwide, there is only one company, Iogen Corporation, Canada (http://www.iogen.ca), produce bio-ethanol at commercial scale using wheat straw and corn stover. In India, despite plentiful availability of biomass, there is no commercial ethanol production plant from lingocelluloses. The key to the establishment of a commercial bio ethanol production facility and the reduction in capital thereof, resulting in lessening of operating costs from each of the units of operations will be an achievement par standards of excellence and utility! Industry attention, not just the accolades is required for searching the answers to the fast paced fuel drain phenomena threatening to takeover into as a major crisis or even worse an economic depression by the end of 21st century. For a flourishing bio ethanol industry, government support is critical in correcting tax anomalies, exemption from excise and sales tax, deregulation of feedstock and its pricing and encouraging pilot projects and R&D work on bio ethanol. Advances in pre-treatment by acid catalyzed hemicellulose hydrolysis or employing an integrated approach in the form of consolidated bio processing with application of novel, tailored cocktails of enzymes for the cellulose breakdown coupled with the recent development of genetically engineered microorganism those ferment all possible sugars in biomass to ethanol at high productivity are the major key factors to make bio ethanol program successful at commercial scale. The other important aspect by deploying the bio ethanol option is its benefit to the environment. Ethanol is one of the best tools to fight vehicular pollution; its clean burning reduces the harmful gasses and particulate emissions that pose health hazard. The implementation of bio ethanol policy can be helpful in improving in environment and rural economic development with sustainable agricultural practices and enhancement of biomass feedstock conscious usage towards the bio ethanol industry will bring up the new age farmer into the limelight and horizon of activities and threshold of business to become renewed with options to deal better in life. A better farmer will ultimately usher in a better livelihood for one and all.

Acknowledgements

The authors place on records their appreciation to BPCL-OUAT Bio-fuel Project implemented in OUAT, Bhubaneswar for providing valuable support in preparation of the paper.

References

1. Alzate CAC, Sánchez Toro OJ. Energy consumption analyses of integrated flow sheets for production of fuel ethanol from lignocellulosic biomass. Energy (In Press), 2005.
2. Aristidou A, Penttilä M. Metabolic engineering applications to renewable resource utilization. Curr. Opin.Biotechnol. 2000; 11:187-198.
3. Bull SR, Riley CJ, Tyson KS, CostellaR.Total fuel cycle and emission analysis of biomass to ethanol. In: Energy from Biomass and wastes (Klass DL ed.) Institute of gas technology, Chicago. IL. 1992; XVI:1-14.
4. Cysewski GR, Wilke CR. Utilization of cellulosic materials through enzymatic hydrolysis. I. Fermentation of hydrolysate to ethanol and single cell protein. Biotechnol. Bioeng. 1976; 18:1297-1313.
5. Dien BS, Jung HJG, Vogel KP, Casler MD, Lamb JAFS, Iten L *et al*. Chemical composition and response to dilute acid pretreatment and enzymatic saccharification of alfalfa, reed canarygrass and switchgrass. Biomass and bioenergy in press, 2006.
6. Foody B. Ethanol from Biomass: The factors affecting it's commercial feasibility. IogenCorporation, Ottawa, Ontario, Canada, 1988.
7. Gray KA, Zhao L, Emptage M. Bioethanol. CurrOpin Chem Biol. 2006; 10:141-146.
8. Gupta P. Bioconversion of Saccharum spontaneum into fuel ethanol by Pichiastipitis NCIM3498. M.Sc.Thesis. Department of Microbiology, University of Delhi, South Campus, New Delhi, India, 2006.
9. Griffith M, Atlas RM. Preemptive bioremediation: applying biotechnology for clean industrial products and processes. In: R.M. Atlas and J. Philp (eds.). Bioremediation: Applied microbial solutions for real-world environmental cleanup. ASM press, Washington, D.C. 2005, 318-356.
10. Hamelinck CN, Van Hooijdonk G, Faaij APC. Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle- and long-term. Biomass Bioenergy. 2005; 28:384-410.
11. Hamelinck CN, Faaij APC. Outlook for advanced biofuels, Energ. Policy. 2006; 34:3268-3283.
12. Herrera S. Industrial biotechnology- a chance at redemption. Nature Biotechnol. 2004; 22:671-675.
13. Keim CR, Venkatasubramanian K. Economics of current biotechnological methods of producing ethanol. Trends Biotechnol. 1989; 7:22-29.
14. Kheshgi HS, Prince RC, Marland G. The potential of biomass fuels in the context of global climate change; Focus on transportation fuels. Annual Rev. Energy Environ. 2000; 25:199-244.
15. Kwiatkowski JR, McAloon AL, Taylor F, Johnston DB. Modeling the process and costs of fuel ethanol production by the corn dry-grind process. Industrial Crops and Products. 2006; 23:288-296.
16. Lin Tanaka. Ethanol fermentation from biomass resources: Current state and prospects. Appl. Microbiol. Biotechnol. 2006; 69:627-642.
17. Luong JHT, Tseng MC. Process and techno economics of ethanol production by immobilized cells. Appl. Microbiol. Biotechnol. 1984; 19:207-216.
18. Lynd LR, Wang MQ. A product-nonspecific framework for evaluating the potential of biomass-based products to displace fossil fuels. J Ind. Ecol. 2004; 7:17-32.
19. Nigam JN. Bioconversion of water-hyacinth (Eichhornia crassipes) hemicellulose acid hydrolysate to motor fuel ethanol by xylose–fermenting yeast. J Biotechnol. 2003; 97:107-116.
20. Nyguyen QA, Saddler JN. An integrated model for technical and economic evaluation of an enzymatic biomass conversion process. Biores. Technol. 1991; 35:275-282.
21. Subramanian KA, Singal SK, Saxena M, Singhal S. Utilization of liquid biofuels in automotive diesel engines: An Indian perspective. Biomass Bioenergy 2005; 29:65-72.
22. Sun Y, Cheng J. Hydrolysis of lignocellulosic materials for ethanol production: a review Biores Technol. 2002; 83:1-11.
23. Sharma SK. Saccharifixcation and bioethanol production from sunflower stalks and hull. Ph.D thesis. Department of Microbiology, Punjab Agriculture University, Ludhiana, India, 2000.
24. Sanchez G, Pilcher L, Roslander C, Modig T, Galbe M, Liden G. Dilute-acid hydrolysis for fermentation of the Bolivian straw material Pajabrava.Biores. Technol.2004; 93:249-256.
25. Wingren A, Galbe M, Zacchi G. Techno-Economic evaluation of producing ethanol from softwood: comparison of SSF and SHF and identification of bottlenecks. Biotechnol. Prog. 2003; 19:1109-17.
26. Yu ZS, Zang HX. Ethanol fermentation of acid hydrolysed cellulosic pyrolysate with Saccharomyces cerevisiae. Biores. Technol. 2004; 93:199-204.
27. Von Sivers M, Zacchi G, Olsson L, Hahn-Hägerdal. B: C analysis of ethanol production from willow using recombinant Escherichia coli. Biotechnol Prog.1994; 10:555-60.
28. Wayman M, Parekh SR. Biotechnology of biomass conversion; Fuels and chemicals from renewable resources. Open University Press Milton Keynes, 1990.
29. Ward OP, Singh A. Bioethanol technology: developments and perspectives. Adv. Appl. Microbiol. 2002; 51:53-80.
30. Wilke CR, Yang RD, Scamanna AF, Freitas RP.Raw material evaluation and process development studies forconversion of biomass to sugars and ethanol. Biotechnol. Bioeng. 1981; 23:163-183.
31. Wright JD. Ethanol from lignocellulosics: An overview. Energy Prog. 1988; 84:71-80.
32. Wooley R, Ruth M, Sheehan J, Ibsen K, Majdeski H, Galvez A. Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis: current and futuristic scenarios. NREL/TP-580-26157, National Renewable Energy Laboratory, Golden, CO, 1999.
33. Wyman CE, Hinman ND. Ethanol. Fundamentals of production from renewable feedstocks and use as transportation fuel. Appl Biochem. Biotechnol. 1990; 24(25):735-75.