

An Analysis over Challenges and Feasibility of Cellulosic Bio-fuels in IRAN and over the World

Pooya Naderi¹, Majid Naderi², Navid Najafi³

^{1,3}Young Researchers and Elite Club, Najafabad Branch, Islamic Azad University, Isfahan, Iran

²RE Engineering Section, Maintenance Technical Office, ISFAHAN'S MOBARAKEH STEEL Co.

Received: June 10 2013

Accepted: July 10 2013

ABSTRACT

As the worldwide demand for fuels and chemicals surges and petroleum deposits are depleted, the need for an alternative fuel becomes more significant. Biofuels such as ethanol (in Brazil and the U.S) and biodiesel (in Germany) are more being used, but one of the challenges could be the usage of food-producing farmlands for feedstock production for biofuel industries. One of the solutions can be the utilization of agricultural residues. Agricultural residues are expected to serve as a major biofuel feedstock, and their potential low cost and current availability can be particularly important in the near term. Because the rapidly evolving tools of biotechnology can radically lower conversions costs and enhance yields, biological processing presents a particularly promising approach to converting these solids into liquid fuels that better fit our transportation infrastructure while providing unparalleled environmental, economic, and strategic benefits. Yet there are some challenges about biofuels production, their compatibility with current vehicles and their impacts on exhaust gases which should be taken into account.

KEYWORDS: biofuels, agricultural residues, challenges.

1. INTRODUCTION

Cellulosic biomass provides a truly unique resource for large-scale sustainable production of liquid fuels that integrate into our existing transportation infrastructure, and no other raw material can match its potential impact and cost [1];[2]. Cellulosic materials can be used as the best alternative for replacing food grains in ethanol production. Proponents of cellulosic ethanol point out that its production generates a higher net energy gain and a lower level of greenhouse gas emissions relative to grain based ethanol, due in part to the fact that a higher portion of the feedstock material is converted to fuel. As a result, the past decade has seen a tremendous increase in research related to ethanol production from feed stocks such as corn stover, switch grass, rice hulls, wheat straw, landscape waste, paper processing waste, food processing waste, and sugarcane waste [3]. A wide variety of cellulose-based biomass wastes and byproducts are available for conversion to biofuels. These include:

- Agricultural residues (corn stalks and cobs, straws, cotton gin trash, palm oil wastes, etc.)
- Paper (paper mill sludge, recycled newspaper, sorted municipal solid waste, etc.)
- Wood waste (sawdust, woodchips, pruning, etc.)
- Landscape waste (leaves, grass clippings, vegetable and fruit wastes, etc.)

Most of these materials are available at very low cost, and some even command tipping fees associated with their disposal as wastes [4].

FEEDSTOCK ANALYSIS AND BIOFUEL PRODUCTION

The various feed stocks that can be used for the production of biofuels may be classified into three groups: cellulosic biomass, sugar and starchy crops, and oil-containing or oil-producing plants. Cellulosic biomass is made up of very complex sugar polymers that are not usually used as a source of human food which differs it from other groups. Cellulosic biomass includes a wide range of heterogeneous solid materials such as agricultural residues comprising leftover material from crops such as rice straw, or coconut coir, or the stalks, leaves and husks of corn plants and forestry wastes such as chips and sawdust from lumber mills, dead trees, and tree branches, etc[5]. Typically, cellulosic biomass is composed of about 40%-50% cellulose, 20%-30% hemicelluloses, 10%-25% lignin, and lesser amounts of minerals, oils, free sugars, starches, and other compounds [6]. Cellulose is a complex sugar polymer, or a polysaccharide, and is made from the six-carbon sugar called glucose. Because of its crystalline structure, it is resistant to hydrolysis, the chemical reaction that enables the production of simple, fermentable sugars from a polysaccharide. Hemicelluloses is also a complex polysaccharide that is made from a variety of five-carbon and six-carbon sugars. Although it is relatively easier to hydrolyze into simple sugars compared to cellulose, the sugars that are produced, however, are not easily fermented to ethanol. Lignin provides structural integrity and strength in plants. It remains as the residual material after the sugars in the biomass have been converted to ethanol [5]. Cogeneration systems could be implemented to burn lignin and other co-products to simultaneously produce steam and electricity, thereby reducing electricity requirements from external sources and providing electrical power for additional bio-refining operations [4]. The structural composition of various types of cellulosic biomass materials are given in Table 1.

Table 1. Composition of various types of cellulosic biomass materials (% dry weight) [7]

Material	Cellulose	Hemicelluloses	Lignin	Ash	Extractives
Algae (green)	20 – 40	20 – 50	–	–	–
Grasses	25 – 40	25 – 50	10 – 30	–	–
Hardwoods	45 ± 2	30 ± 5	20 ± 4	0.6 ± 0.2	5 ± 3
Softwoods	45 ± 2	27 ± 2	28 ± 3	0.5 ± 0.1	3 ± 2
Cornstalks	39 – 47	26 – 31	3 – 5	12 – 16	1 – 3
Wheat straw	37 – 41	27 – 32	13 – 15	11 – 14	7 ± 2
Newspapers	40 – 55	25 – 40	18 – 30	–	–
Chemical pulps	60 – 80	20 – 30	2 – 10	–	–

In Iran, there is the possibility of biofuel production from feed stocks like wheat straw, sugarcane, and many other kinds of cellulosic biomass and agricultural residues. For instance, sugarcane is grown massively in south western areas of Iran and can be a good feedstock for ethanol production.

In order to produce ethanol from cellulosic biomass, complex cellulosic carbohydrates must be converted into simple sugars, which can then be fermented to ethanol by a variety of micro organisms. Conversion of cellulose to sugars can be done either through dilute or concentrated acid hydrolysis processes or enzymatic processes. A decrystallized cellulosic mixture of acid and sugars reacts in the presence of water to produce individual sugar molecules (hydrolysis). The product from this hydrolysis is then neutralized, and yeast fermentation is used to produce ethanol when low cost dilute acid is used to catalyze the hydrolysis reaction, biomass is impregnated with dilute sulfuric acid solution and treated with steam at temperatures ranging from 140 to 260 degrees centigrade [8]. On the other hand, the concentrated acid process operates at lower temperatures (100-120), and high yields of sugars are obtained with little production of degradation products. At last, enzymatic conversion of cellulose to sugars offer s some promising advantages over acid hydrolysis. Sugar yields are limited during acid hydrolysis because sugars are also converted to degradation products. “Cellulose” is a multi component enzyme system that catalyzes cellulose hydrolysis and is 100% selective for conversion of cellulose to glucose; high yields are therefore possible. In addition, enzymatic processes are safer and more environmentally friendly.

2. CHALLENGES AND FEASIBILITY

In order to produce and use biofuels as an alternative fuel from agricultural wastes there are many challenges to deal with and many problems to solve in addition to the benefits that they have. Issues like feedstock cost, production cost, environmental considerations, compatibility with current vehicles, choosing the best biofuel for a country or region, and many other parameters can affect the feasibility of a biofuel.

Because feedstock costs are dominant in processing economics, it is critical to seek those that are low in cost for first applications while being sufficiently abundant. However, high product yields and ease of processing are also vital to minimizing costs, while sufficient amounts must be available to support a large facility to achieve reasonable economies of scale [2]. Competition for feed stocks and harvesting and transport costs are critical, particularly for initial commercial ventures. For example, as the stalks left after extraction of sugar from sugarcane are already at a central location, no additional costs are incurred for collection and transport. However, these materials have value as a fuel for generating process heat and possibly electricity, which still must be taken into consideration. Furthermore, progress in improving cellulosic conversion technology can reduce the cost of production.

Agricultural and forestry and organic portions of municipal solid waste can have a negative impact on the environment as they decay. On the other hand, converting these residues to ethanol can offer immediate and sustained GHG(Greenhouse Gases) advantages and simultaneously enhance domestic fuel production [9]; [10]; [11]; [12]; [13]; [14]; [15]; [16]. Even if GHG benefits are demonstrable, other sustainability and environmental considerations must be addressed for use of agricultural residues. In particular, removing agricultural residues from the land can impact soil cultivation and the needs for fertilizer, pesticides, and other chemicals, all of which can impact soil, water quality, air quality, site productivity, and GHG emissions[17]; [16].

Table 2 shows the emission impacts of gasoline and diesel fuel blends with 15 vol % ethanol. The use of blends of ethanol with gasoline and diesel fuel is preferred in internal combustion engines in order to decrease carbon monoxide and carbon dioxide emissions. The total net emissions of carbon dioxide from gasohol and diesohol blends are considerably less than those of gasoline and diesel fuel.

Table 2. Emission impacts of gasoline and diesel fuel blends with 15 vol% ethanol (percent change in emissions) [18]

Emission type	Gasohol	Diesohol
Total unburned hydrocarbons	-27	-24
Carbon monoxide	-32	-29
Carbon dioxide	-43	-45
Particulate matter	-21	-18
Sulfates	-15	-15

Gasohol has higher octane, or antiknock, properties than gasoline and burns more slowly, coolly, and completely, resulting in reduced emissions of some pollutants, but it also vaporizes more readily, potentially aggravating ozone pollution in warm weather [18].

Low saturated vapor pressure of methanol and ethanol reduces fire hazard inflammability during use of these alcohols on the one hand, but renders start of a cold engine difficult, on the other hand, because the part of the fuel occurring in the vaporous state is the one that takes part in the ignition process. High ignition temperature (flash point), in conjunction with low saturated vapor pressure, drastically impairs performance and ecological (environmental) properties of the ICE (Internal Combustion Engines), especially in cold climate because even at +10°C it becomes impossible to start the ICE. Note that automobile gasoline ensures normal start of the ICE at temperatures down to -35°C. In order to offset the poor start qualities of alcohols, up to 10% light hydrocarbons or low-molecular ethers are added to them, which helps lower the start temperature down to -25°C.

The combustion heat of methanol and ethanol is almost twice as low as the combustion heat of conventional gasoline. Low combustion heat reduces engine power because the kinetic energy of the combustion products falls, and the torque (torsional moment) of the engine declines steadily. Lower combustion heat of a fuel leads to a number of additional negative consequences. The time of heating up of the ICE to the operating temperatures increases many times. The motion on an insufficiently heated engine is extremely difficult (in some cases, contraindicative) because in that case the ICE runs unsteadily. Wide expansion clearances in the friction joints give rise to impact loads and faster wear of the contact faces[19].

While oxygenated fuels have been promoted for their ability to decrease certain air toxics, multiple studies have reported higher emissions of the hazardous air pollutants acetaldehyde and formaldehyde linked to increased ethanol content in fuels [20]; [21]; [22];[23]; [24]; [25].

From the infrastructure perspective, ethanol transportation and distribution is a significant economical and technical challenge, since current pipelines cannot transport ethanol.

In 2007 the DOE (Department of the Environment), the National Renewable Energy Laboratory (NREL) and the Oak Ridge National Laboratory initiated a test program to evaluate the impact of E15 and E20 ethanol blends on legacy vehicles and small non-road engines [26]; [22]. The DOE data, together with the findings of an E20 study commissioned by the Australian government and published in 2004, concurred in reporting increased exhaust and catalyst temperatures associated with ethanol fuels blends, especially for older vehicles [27]; [22]. Modern vehicles equipped with oxygen sensor-based, closed-loop control systems are calibrated during manufacturing to appropriately compensate for higher levels of oxygen in ethanol blends.

Attempts are underway to produce alternative renewable liquid biofuels and chemical feedstocks that are superior to ethanol. Butanol is one such biofuel because it has greater energy content, is more miscible with diesel, is less corrosive, and has a lesser vapor pressure and flash point than ethanol does. In addition, because of its solubility characteristics, it can be transported in existing fuel pipelines and tanks. But the major problem is the cost of substrate which can be reduced by using agricultural residues.

3. CONCLUSIONS

With continuous world population growth and energy demand, current production of liquid biofuel (ethanol) from food crops such as corn and sugar cane is unsustainable. The use of agricultural residues to produce liquid biofuels holds great interest as a means for generating sustainable transportation fuel and feedstock chemicals. But in usage and production of biofuels like ethanol some factors should be considered in order to make them more feasible. For instance, using the right blending percentage of ethanol with gasoline so as to reduce the GHG emissions or production of butanol as a more compatible fuel with engines.

REFERENCES

1. Lynd, L.R., M.S. Laser, D. Bransby, B.E. Dale, B. Davison, R. Hamilton, M. Himmel, M. Keller, J.D. McMillan, J. Sheehan, and C.E. Wyman. 2008. How biotech can transform biofuels. *Nature Biotechnology*, 26(2):169-172.
2. Yang, B. Yanpin Lu, and Charles E. Wyman. 2010. *Cellulosic Ethanol from Agricultural Residues, Biofuels from Agricultural Wastes and Byproducts*. ISBN 978-0-8138-0252-7
3. U.S. Department of Energy, National Renewable Energy Laboratory. 2007. *Research Advances: Cellulosic Ethanol: NREL Leads the way*. Golden, CO: National Renewable Energy Laboratory. <http://www.nrel.gov/biomass/pdfs/407.42.pdf>.
4. Timothy C. Lyndsey. 2010. *Conversion of Existing Dry-Mill Ethanol Operations to Biorefineries, Biofuels from Agricultural Wastes and Byproducts*. ISBN 978-0-8138-0252-7
5. Dr. Filemon A. Uriarte, Jr. 2010. *Biofuels from Plant Oils* Executive Director of ASEAN Foundation Published (2010) by the ASEAN Foundation, Jakarta, Indonesia. ISBN No. 978-979-19684-1-6
6. Wyman, C.E., ed. 1996. *Handbook on Bioethanol: Production and Utilization*. Applied Energy Technology Series. Washington, DC: Taylor & Francis.
7. Demirbas, 2005. Bioethanol from cellulosic materials: A renewable motor fuel from biomass. *Energy Sources* 27:327-337.
8. Katzen, R. and D.J. Schell. 2006. Lignocellulosic feedstock biorefinery: History and plant development for

- biomass hydrolysis. in: *Biorefineries –Industrial Processes and Products, Status Quo and Future Directions. Volume 1*, edited by B. Kamm, P. Gruber, and M. Kamm, pp. 129-138. Weinheim, Germany: Wiley-VCH.
9. Paustian , K., C.V. Cole, D. Sauerbeck, and N. Sampson. 1998. CO2 mitigation by agriculture: An overview. *Climatic Change*, 40(1):135-162.
 10. Tilman, D.,J. Fargione, B. Wolff, C. D'Antonio, A. Dobson, R. Howarth, D. Schindler, W.H. Schlesinger, D. Simberloff, and D. Swackhamer. 2001. Forecasting agriculturally driven global environmental change. *Science*, 292(5515):281-284.
 11. DiPardo, J. 2002. Outlook for biomass ethanol production and demand. Available at www.eia.doe.gov/oiaf/analysispaper/pdf/biomass.pdf (verified 13 July 2008). Energy Inf. Admin., Washington, DC.
 12. Wyman, C.E. 2003. Potential synergies and challenges in refining cellulosic biomass to fuels, chemicals, and power. *Biotechnology Process*, 19(2):254-262.
 13. Zhang, Y., S Habibi, H.L. MacLean. 2007. Environmental and economic evaluation of biorefinery in Ontario, Canada. *Journal of the Air & Waste Management Association*, 57(8):919-933.
 14. BR&Di. 2008. Increasing feedstock production for biofuels. The Biomass Research and Development Board. www.brdisolutions.com.
 15. Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. Land clearing and the biofuel carbon debt. *Science*,319(5867):1235-1238.
 16. Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J. Smith.2008. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society of London, Series B*, 363(1492):789-813.
 17. Kim, S. and B.E. Dale.2004. Cumulative energy and global warming impact from the production of biomass for biobased products. *Journal of Industrial Ecology*, 7(3/4):147-162.
 18. Demirbas, A. 2007. Gasoline and diesel fuel blends with alcohols. *Energy EduSciTechnol* 19:87–92.
 19. K. E. Pankin, Yu. V. Ivanova, R. I. Kuz'mina, and S. N. Shtykov *Chemistry and Technology of Fuels and Oils*, Vol. 47, No. 2, May, 2011 (Russian Original No. 2, March-April, 2011)
 20. Ban-Weiss GA, McLaughlin JP, Harley RA, Kean AJ, Grosjean E, Grosjean D. 2008. Carbonyl and nitrogen dioxide emissions from gasoline- and diesel-powered motor vehicles. *Environ Sci Technol*42 (11): 3944-50.
 21. Black F, Tejada S, Gurevich M. 1998. Alternative fuel motor vehicle tailpipe and evaporative emissions composition and ozone potential. *J Air Waste ManagAssoc* 48(7): 578-91.
 22. DOE. 2009. Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 – Updated. Knoll, K., West, B.H., Clark, W., Graves, R.L., Orban, J., Przesmitzki, S., Theiss, T.J. NREL/TP-540-43543 ORNL/TM-2008/117. Available: http://feerc.ornl.gov/publications/Int_blends_Rpt1_Updated.pdf.
 23. Grosjean D, Grosjean E, Moreira LF. 2002. Speciated ambient carbonyls in Rio de Janeiro, Brazil. *Environ SciTechnol* 36(7): 1389-95.
 24. Whitney K, Fernandez T. 2007. Characterization of Cold Temperature VOC and PM Emissions from Flex Fuel Vehicles Operating on Ethanol Blends. In: 17th Coordinating Research Council (CRC) On-Road Vehicle Emissions Workshop. San Diego, CA. Williams F. 2008. Ethanol May be Harmful to Your Lawnmower. Available: <http://www.thetruthaboutcars.com/ethanol-may-be-harmful-to-your-lawnmower/>
 25. Winebrake JJ, Wang MQ, He D. 2001. Toxic emissions from mobile sources: a total fuel-cycle analysis for conventional and alternative fuel vehicles. *J Air Waste ManagAssoc* 51(7): 1073-86.
 26. Bechtold R, Thomas JF, Huff SP, Szybist JP, Theiss TJ, West BH, et al. 2007. Technical Issues Associated with the Use of Intermediate Ethanol Blends (>E10) in the U.S. Legacy Fleet: Assessment of Prior Studies. Oak Ridge National Laboratory ORNL/TM-2007/37. Available: http://www.osti.gov/bridge/product.biblio.jsp?query_id=0&page=0&osti_id=936789
 27. Australian Government. 2004. Department of the Environment, Water, Heritage and the Arts. 20% Ethanol (E20) Report. Available: <http://www.environment.gov.au/atmosphere/fuelquality/standards/ethanol/e20.html>