Techno-economic Feasibility of Bioethanol Production for Fossil Fuel-Fired Generating Plant in Nigeria

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Abstract

This paper examines the feasible and economic technology involved in production of bioethanol for fossil fuel-fired generating power plant in Nigeria. This work focuses on exploitation of recent development in the field of bioethanol production technology and devises feasible method for manufacturing bioethanol for both fuel-fired plants and blending bioethanol with oil-fuels for transportation in Nigeria. Implementation of this work will reduce environmental pollution and CO_2 emission (which increases the global warming); and minimizes rapid depletion of fossil fuels as well as ensuring generation of clean, efficient, reliable, safe and affordable electricity in Nigeria.

Key Words: *Fermentation, Saccharification, Hydrolysis, Distillation, Rectification*

INTRODUCTION

Today, oil based fuels have became very popular in production and technology as well as in transportation areas. Rapid growths of civilization and sophistication have triggered ever-increasing demand for energy; and engagement in energy and resource race that blossoms to energy crisis. As a result, the demand for oil has increased with sharp escalation in the prices of oil and inability of the energy players to keep pace with the demand for electric energy (Anumaka, 2012). An energy-deficient society is weak and cannot make tangible economic advancement (Anuma & Okeke, 2012). Electrical energy has captured the highest level of energy hierarchy. It is primarily the electrical energy that the wheels of progress moving at accelerating pace (http://www.makebiofuel.co.uk/news; The Worldwatch Institute, 2007). But, more than 70% of the generated energy is powered by fossil fuels. This effect has improved the commercial viability of alternatives to oil. In fact, the entire world is threatened by this ugly trend because of rapid depletion of fossil fuels, and there is premonition that the fossil fuel will run out if not checked. Moreover, environmental pollution produced by fossil fuel-fired power plants has hazardous implications on human beings, socio-economic development and global warming. Despite the above challenge, fossil fuel-fired generating plants have low energy conservation efficiency, not more than 35%- 40%. Hence, there is need for intensive research to improve the thermal efficiency of fossil fuel-fire turbine units, which this work attempted to explore.

Bioethanol

Bioethanol is a renewable fuel. It reduces greenhouse gas emissions compared to gasoline (petrol). When bioethanol is combusted (burnt), it effectively returns carbon dioxide back to the atmosphere, which had been taken out relatively recently as the biomass grew. Bioethanol refers to ethanol liquid which is made from common crops including sugar cane and corn. It is a form of renewable energy that can be produced from agricultural feedstocks. Bioethanol or ethyl alcohol (C_2H_5OH) is a clear colourless liquid; it is biodegradable, low in toxicity and causes little environmental pollution if spilt. Bioethanol burns to produce carbon dioxide and water. It is a high octane fuel and has replaced lead as an octane enhancer in petrol. Bioethanol is a renewable energy source because the energy is generated by using a resource, sunlight, which cannot be depleted. Ethanol can be made from any crop or plant that contains a large amount of sugar or components that can be converted into sugar, such as starch or cellulose. Figure 1 illustrates the bioethanol source crops. As their names imply, sugar beets and sugar cane contain natural sugar. Crops such as corn, wheat and willow barley contain starch that can be easily converted to sugar. Most trees and grasses are made of cellulose, which can also be converted into sugar, although not as easily as starch (Http:www.esru.strath.ac.uk; Http://www.cropenergies.com; Http://www.erec.org; Fox & Mulvihill, 1982; Tucker &Woods 1995).

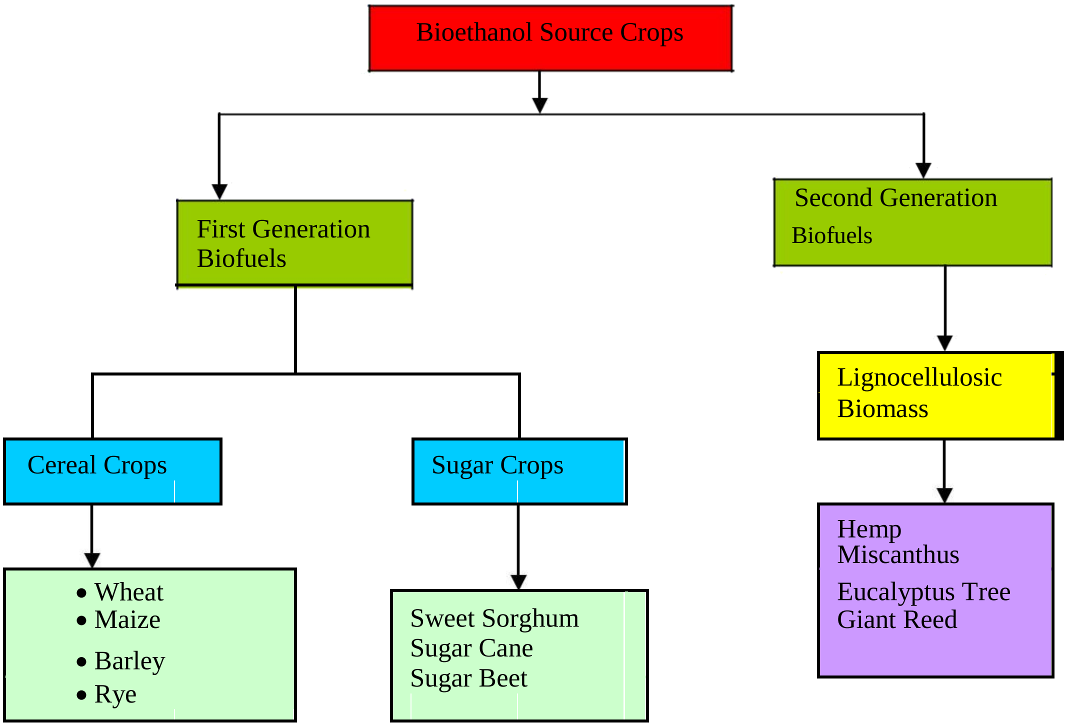

Figure 1. The bioethanol source crops

There are three main methods of producing bioethanol from biomass materials (Http://www.ineos.com)

1. Conventional fermentation of sugars obtained from sugar and starch crops
2. Hydrolysis of cellulose to sugars using acid or enzymes followed by fermentation of the sugars
3. Gasification of any biomass to syngas followed by conversion to bioethanol

The conventional creation of bioethanol starts with photosynthesis of feedstock, such as sugar cane or a grain such as maize (corn). Bioethanol fuel is mainly produced by the sugar fermentation process, although it can also be manufactured by the chemical process of reacting ethylene with steam.

BIOETHANOL PRODUCTION DESIGN AND TECHNOLOGY

The production of bioethanol from biomass is manufactured basically by the solid combustion, gasification and fermentation of plants containing sugar and starch, which takes place in the steps indicated in figure 2.

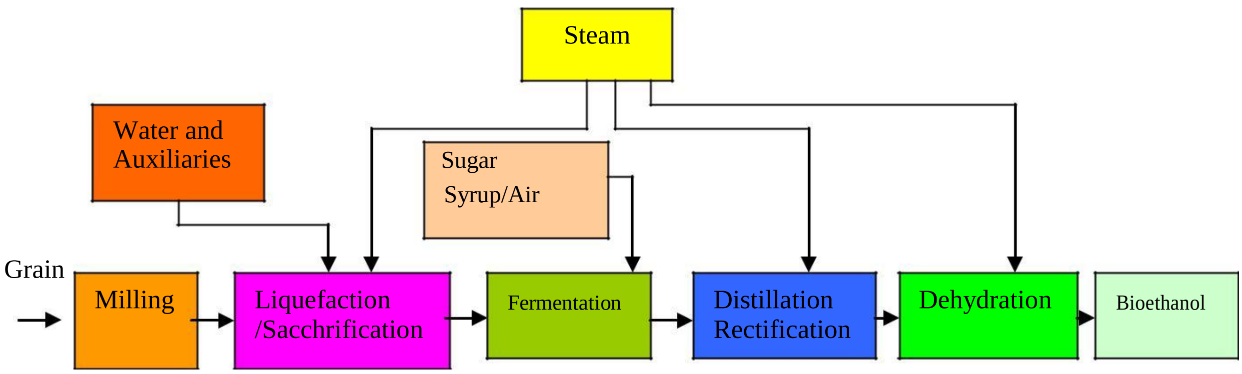

Figure 2. Proposed Nigerian Bioethanol production process

Milling

Milling is the grinding of the grain so that it can be easily used for a particular purpose. **Milling** (dry and wet) is employed, depending on the cereal itself and on the eating purpose of the consumer. There are two types of milling dry milling or the wet milling process (Rozsa, 1976; Tucker &Woods 1995). The objective of milling is separation of the floury edible endosperm from the various branny outer coverings and elimination of the germ, or embryo. Milling methods used in most of African countries and Asia are primitive, but large mills operate in Japan and some other advanced countries of the world. The sugar cane for instance goes through the crusher, a set of roller mills in which the cane cells are crushed and juice extracted. As the crushed cane proceeds through a series of up to eight four-roll mills, it is forced against a countercurrent of water known as water of maceration or imbibitions (http://www.techmach.co.za)

Dry Milling Process. This involves the mechanical crushing of the cereal grains to release the starch components. The dry milling process involves cleaning and breaking down the corn kernel into fine particles using a hammer mill process. This creates a powder with a course flour type consistency. The powder contains the corn germ, starch and fibre. In order to produce a sugar solution the mixture is then hydrolyzed or broken down into sucrose sugars using enzymes or a dilute acid. The mixture is then cooled and yeast is added in order to ferment the mixture into ethanol. The dry milling process is normally used in factories producing less than 50 million gallons of ethanol every year.

Wet Milling Processes. In the wet milling process, the corn kernel is steeped in warm water; this helps to break down the proteins and release the starch present in the corn and helps to soften the kernel for the milling process. The corn is then milled to produce germ, fibre and starch products. The germ is extracted to produce corn oil and the starch fraction undergoes centrifugation and saccharifcation to produce gluten wet cake. The ethanol is then extracted by the distillation process. The wet milling process is normally used in factories for producing several hundred million gallons of ethanol every year.

Saccharification/ Liquification

This involves making sugar from the starch reserve: convert into a simple soluble fermentable sugar by hydrolyzing a sugar derivative or complex carbohydrate (http://www.thefreedictionary.com/saccharifying). It is the hydrolysis of soluble polysaccharides to form simple sugar. In this stage the diastatic enzymes start acting on the starches, breaking them up into sugars (hence the term saccharification). The amylases are enzymes that work by hydrolyzing the straight chain bonds between the individual glucose molecules that make up the starch chain. These starches are polar molecules and have different ends (Think of a line of batteries.) An amylopectin differs from an amylose (besides being branched) by having a different type of molecular bond at the branch point, which is not affected by the diastatic enzymes.

Liquifaction, generally refers to the process of becoming a liquid or liquid-like. In this case, the feedstock is converted into liquid like substance. It involves continuous enzymatic liquefaction of corn starch at high concentration and subsequently saccharification to glucose. The process appears to be quite efficient for conversion of starch to glucose and enzymatic liquefaction and should be readily adaptable to industrial fermentation processes.

Fermentation

Fermentation specifically refers to the chemical conversion of sugars into bioethanol, a process which is used to produce alcoholic beverages such as wine, beer, and cider. At this stage, Fermentation of the mash using yeast occurs, whereby the sugar is converted into bioethanol and CO_2 released. The hydrolysis process breaks down the cellulosistic part of the biomass or corn into sugar solutions that can then be fermented into bioethanol. Yeast is added to the solution, which is then heated. The yeast contains an enzyme called invertase, which acts as a catalyst and helps to convert the sucrose sugars into glucose and fructose ($C_6H_{12}0_6$). Bioethanol is also produced by microbial fermentation of the sugar. Microbial fermentation will currently only work directly with sugars. Two major components of plants, starch and cellulose, are both made up of sugars, and can in principle be converted to sugars for fermentation (Eliasson & Larsson, 1993; Cook, 1994).

Currently, only the sugar (e.g. sugar cane) and starch (e.g corn) portions can be economically converted. During bioethanol fermentation, glucose and other sugars in the corn (or sugarcane or other crops) are converted into ethanol and carbon dioxide (Rozsa, 1976)

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2\ CO_2 + heat$$

Like any fermentation reaction the fermentation is not 100% selective and other side products such acetic acid, glycols and many other products are formed to a considerable extent and need to be removed during the purification of the ethanol. The fermentation takes place in aqueous solution and the resulting solution after fermentation has an ethanol content of around 155. The ethanol is subsequently isolated and purified by a combination of adsorption and distillation techniques. The purification is very energy intensive.

During combustion ethanol reacts with oxygen to produce carbon dioxide, water, and heat:

$$C_2H_5OH + 3\ O_2 \longrightarrow 2CO_2 + 3\ H_2O + heat$$

Starch and cellulose are molecules that are strings of glucose molecules. It is also possible to generate ethanol out of cellulosic materials. However, a pretreatment is necessary that splits the cellulose into glucose molecules and other sugars which subsequently can be fermented. The resulting product is called cellulosic ethanol, indicating its source.

Ethanol may also be produced industrially from ethane (ethylene), by hydrolysis of the double bond in the presence of catalysts and high temperature.

$$C_2\ H_4 + H_2O \longrightarrow C_2H_5OH$$

The by far largest fraction of the global ethanol production, however, is produced by fermentation.

Distillation and Rectification

Distillation is a process involving the conversion of a liquid into vapour that is subsequently condensed back to liquid form. Distillation is used to separate liquids from nonvolatile solids, as in the separation of alcoholic liquors from fermented materials, or in the separation of two or more liquids having different boiling points.

This process entails concentration and cleaning the ethanol produced by distillation. Distillation separates the alcohol from the other constituents of the mash. The ethanol, which is produced from the fermentation process, still contains a significant quantity of water, which must be removed. This is achieving by using the fractional distillation process. The distillation process works by boiling the water and ethanol mixture. Since ethanol has a lower boiling point (78.3C) compared to that of water (100C), the ethanol turns into the vapour state before the water and can be condensed and separated.

In the rectification process this alcohol is then cleaned again. The dehydration- also referred to as drying- of the alcohol then removes virtually all the waster it contains. The result is bioethanol with an extremely high purity of 99.7 vol. -%.

Dehydration

Dehydration is from the Greek *hydor* (water) and the Latin prefix *de-* implies deprivation, removal, and separation that occurs when more water and fluids are exiting from the substance. For the ethanol to be usable as a fuel, water must be removed. Most of the water is removed by distillation. The purity is limited to 95-96% due to the formation of a low-boiling water-ethanol zoetrope. This may be used as fuel alone but unlike anhydrous ethanol it is immiscible in Petrol meaning it cannot be mixed i.e. E85. The water fraction is typically removed in further treatment in order to burn with in combination with petrol in petrol engines. Currently, the most widely used purification method is a physical absorption process using a molecular sieve. Another method, azeotropic distillation, is achieved by adding the hydrocarbon benzene which also denatures the ethanol (to render it undrinkable for duty purposes). A third method involves use of calcium oxide as a desiccant.

FEASIBILITY AND JUSTIFICATION OF PROPOSED NIGERIAN BIOTHANOL PRODUCTION PROCESS

Leading Economics

The outstanding energy efficiency, selectivity to the bioethanol and feedstock flexibility of advanced bioethanol production process result in highly cost-competitive production of ethanol.

Feedstock Flexibility

Unlike conventional bioethanol technologies, which use food crops, or even the emerging cellulosic fermentation technologies, which can convert cellulose and hemi-cellulose but not lignin, the present bioehanol production design and technology shown in figure 2.0 can convert all ligno-cellulosic materials as well as other carbon materials into ethanol.

Energy Efficient

The designed technology for the Nigerian bioethanol production comprises of a thermo-chemical process and a low temperature, low pressure biochemical process (bacterial fermentation) with excellent heat integration throughout delivers high energy efficiency.

Biocatalyst Advantages

The proposed Nigerian bioethanol technology has low cost biocatalyst, regenerates itself, tolerant to impurities in the syngas, has extremely high selectivity to ethanol and operates at low temperature and pressure.

Security of Energy Supply

The abundant feedstock endowed in Nigeria can enables the country to produce sufficient bioethanol for power generation and road transportation.

Climate Friendly

When the bioethanol is used as a road transport fuel, the greenhouse gas (GHG) emissions are reduced by at least 80% compared to other fossil fuels.

Society

A localized approach that reduces wastes going to landfill and air pollution, creates jobs, generates tax revenue and safely produces renewable fuel and clean energy.

Reduced Pressure on Land Use

Significant greenhouse gas (GHG) emission savings can be achieved from the road transport sector without increasing pressure on land use, or increasing agrichemical use (e.g. fertilizers and pesticides). The diversion of organic wastes from landfill avoids harmful effects of landfill.

World Changing Technology

This INEOS Bio process has the potential to make a substantial contribution across many policy issues whilst creating significant value to society.

CONCLUSION

Sequel to excessive depletion of fossil fuels which has resulted drastic emission of greenhouse gas (GHG), with resultant increment in the global warming. It becomes paramount to devise a renewable and alternative source of energy and power generating system that will minimize the greenhouse emission ensure generation of clean, efficient and reliable power supply. This work has exploited the above challenges and will ensure economic use of vast arable agricultural land to develop rural areas, create employment opportunity; as well as exploiting strategy and modern technology.

RECOMMENDATIONS

The following recommendations are proffered:
Sequel to dearth of bioethanol technical know-how in the developing countries countries including Nigeria, the authors hereby recommended establishment of bioethanol production plant.

It is recommended that the developing countries should create awareness and partner with the United Nations Economic Commission for both economic assistance and launching bioethanol production programmes.

Creation of bioethanol incentive agency (BIA) that can render financial assistance to the prospective bioethanol investors.

The government should formulate legal and regulatory framework on the authorized feedstock and farmland for various agricultural production activities.

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