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A Global Overview of Biomass Potentials for Bioethanol Production: A Renewable Alternative Fuel

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ABSTRACT

Bioethanol is the principal fuel used as a petrol substitute for road transport vehicles. The high price of crude oil makes biofuels attractive. Brazil has been a front-runner in the use of renewable fuels. Currently the largest producers in the global biofuel industry are the United States and Brazil, where millions of tons of sugar are processed. 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. Domestic production and use of ethanol for fuel can decrease dependence on foreign oil, reduce trade deficits, create jobs in rural areas, reduce air pollution, global climate change and carbon dioxide buildup. Disadvantages of bioethanol include its lower energy density than gasoline, its corrosiveness, low flame luminosity, lower vapor pressure (making cold starts difficult), miscibility with water and toxicity to ecosystems. The main sources of sugar required to produce ethanol are derived from fuel or energy crops. These crops are grown specifically for energy use and include corn, maize and wheat crops, waste straw, willow and poplar trees, sawdust, reed canary grass, cord grasses, Jerusalem artichoke, miscanthus and sorghum plants, wheat grains and/or straw. Although, each source of biomass represents a technological challenge, the diversity of raw materials will allow the decentralization of fuel production with geopolitical, economical and social benefits. This study presents a global overview of bioethanol production, highlighting different feedstocks already in use, their qualities and limitations, also suggesting other potential ones.

Key words: Bioethanol, biomass, renewable energy, feedstocks, biofuel

INTRODUCTION

Due to the finite nature of fossil fuel, the ever increasing oil price and the negative impact on the environment, human and biogeochemical cycles, the world is gradually but systematically shifting towards sustainable energy systems (Anonymous, 2009). As a result, production and use of biofuels have increased. Biomass, as a renewable energy source, refers to living and recently dead biological material that can be used as fuel or for industrial production. In this context, it is often used to refer to plant-based materials, however, biomass can equally apply to both animal and vegetable-derived material (Anonymous, 2009).

Bioethanol from biomass sources is the principal fuel used as a petrol substitute for road transport vehicles. The high price of crude oil makes biofuels attractive (Bryner and Scott, 2006).

Also, because biomass fuels are renewable, they help reduce greenhouse gas emissions from fossil fuels (Ibeto and Okpara, 2010). Bioethanol can be obtained from a variety of feedstocks using cellulosic, starchy and sugar sources. These feedstocks include corn, sugar cane, bagasse, sugar beet, sorghum, switch grass, barley, hemp, potatoes, sunflower, wheat, wood, paper, straw, cotton and other biomass materials. Brazil has been a front-runner in the use of renewable fuels. Currently the largest producers in the global biofuel industry are the United States and Brazil, where millions of tons of sugar are processed (Mobile Emissions Today, 2006). Although, at the moment bioethanol is mainly used in blends with gasoline as E10 and E20 (10 and 20% of ethanol mixed with 90 and 80% gasoline respectively), the demand has soared. For instance, consumption of bioethanol in most countries of the European Union is far greater than the quantity produced in those countries (Wikipedia, 2009a). According to a study by Hart's Global Biofuels Center (a division of Hart Energy Publishing LP, one of the world's largest energy industry publishers), the Global biofuel use may double by 2015 (Johnson, 2009).

Bioethanol production processes: 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.

$$C_2H_6 + H_2O \xleftrightarrow[\substack{500\text{-}600^\circ C \\ 80\text{-}1000\ atm}]{H_2SO_4} C_2H_5OH$$

So far, industries have adopted saccharification and fermentation process for producing bioethanol from woody biomass, where woody biomass is first dissolved into sugars and then the sugars are fermented by yeast and changed into ethanol that is finally refined by distillation. Glucose (a simple sugar) is created in the plant by photosynthesis.

$$6\ CO_2 + 6\ H_2O + light \rightarrow C_6H_{12}O_6 + 6\ O_2$$

During ethanol fermentation, glucose is decomposed into ethanol and carbon dioxide.

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

Fermentation is the slow decomposition by micro-organisms of large organic molecules (such as starch) into smaller molecules such as ethanol. Ethanol fermentation can be described as the biochemical process by which sugar such as glucose, fructose and sucrose are converted into cellular energy thereby producing ethanol and carbondioxide as metabolic waste products. Yeasts carry out ethanol fermentation on sugar in the absence of oxygen. Because the process does not require oxygen, fermentation is classified as anaerobic.

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

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

Bioethanol can be manufactured from numerous sources. They can be produced from raw materials containing fermentable sugars such as sucrose-rich feedstock namely juices, sugarcane and beet etc. They can also be produced from some polysaccharides that can be hydrolyzed for obtaining sugars that can be converted to ethanol (Cardona and Sanchez, 2007). Starch contained in grains is the major polymer used for ethanol production. Lignocellulosic biomass (a complex polysaccharide) is the most promising feedstock considering its great availability and low cost. However large scale commercial production from cellulosic materials is still a major challenge presently.

Bioethanol from molasses: Production of ethanol from molasses constitutes part of the sugar refining process. The overall process consists of the following steps.

- **Crushing:** Sugar cane is chopped at a sugar mill to facilitate handling and processing
- **Sugar cane extraction:** This is effected in a counter current flowing warm water. The solids after extraction (bagasse) containing less than 0.5% sugar are squeezed-dried to remove maximum sugar solution (Liquor)
- **Raw sugar production:** Sugar-containing liquor is concentrated in evaporators. Crystalline sugar is separated in centrifuges. This process is repeated several times yielding raw sugar
- **Fermentation from molasses:** Liquid residue from sugar production (molasses) containing approximately 50% sugar and 50% mineral matter is mixed with yeast and minerals and is used as fertilizer
- **Distillation:** The fermented mash, now called "beer" contains about 10% alcohol as well as all the non-fermentable solids from the feedstock and the yeast cells. The mash is pumped to a continuous flow, multicolumn distillation system where the alcohol is removed from the solids and the water. The alcohol leaves the top of the final column at about 96% strength and the residue mash called stillage is transferred from the base of the column to the co-product processing area
- **Denaturing:** Ethanol that will be used for fuel is denatured at the time of the transport with a small amount (0-5%) of some product such as gasoline to make it unfit for consumption (Beer *et al*., 2006)

Bioethanol from starchy sources: The steps for bioethanol production process from starch feedstock include the following:

- **Milling:** The feedstock is passed through mills which grind them into flour. The flour is sieved to extract the pure starch (dry milling) or mixed with water, ground in the mill and sieved alternatively to extract the pure starch after which the starch is dried in the open sun (wet milling)
- **Liquefaction:** The meal or pure starch is mixed with water and alpha-amylase and passed through cookers where the starch is liquefied. Heat is necessarily applied to enable the liquefaction process. Cookers with a high temperature stage (120-150°C) and a lower temperature holding period (90°C) are used. The high temperatures reduce bacteria levels in the mash (Beer *et al*., 2006)
- **Saccharification:** The mash from the cookers is then cooled and the secondary enzyme (glucoamylase) added to convert the liquefied starch to fermentable sugars (dextrose), a process called Saccharification
- **Fermentation:** Yeast is then added to the mash to ferment the sugars to ethanol and carbondioxide. If a continuous process is used, the fermentation mash is allowed to flow through

several fermenters until the mash is fully fermented and then leaves the final tank. In a batch fermentation process, the mash stays in one fermenter for about 48 h before the distillation process is started

- **Distillation:** The fermented mash now called "beer" contains about 10% alcohol as well as the non-fermentable solids from the feedstock and yeast. The mash is subsequently pumped to the continuous flow, multicolumn distillation system where the alcohol is removed from the solids and the water. The alcohol leaves the top of the final column at about 96% strength and the residue mash called stillage is transferred from the base of the column to the co-product processing area
- **Denaturing:** Bioethanol from fuel is then denatured with a small amount (0-5%) of some product such as gasoline to make it unfit for human consumption

Bioethanol from lignocellulosic sources: Lignocellulose is the structural component of plant biomass and can be derived from trees, grasses, cereal, paper waste etc. Lignocellulose also forms a large component of municipal wastes. Both the cellulosic and hemicellulosic portions of the material (which in case of plants may comprise 60-80% of the non-sugar and starch components) can be converted to bioethanol (Beer *et al*., 2006). For instance, sucrose extracted from sugar cane accounts for little more than 30% of the chemical energy stored in the mature plant; 35% is in the leaves and stem tips, which are left in the fields during harvest and 35% are in the fibrous material (bagasse) left over from pressing. This indicates that 70% are concentrated in the parts that are not currently being utilized for ethanol production. This also underscores the need for fast-tracking a technically and economically viable process for bioethanol production from lignocellulosic feedstock. The main challenge in the conversion of biomass into ethanol is the pretreatment step. Due to the structure of the lignocellulosic complex, pretreatment is required for its degradation; the removal of lignin, the partial or total hydrolysis of the hemicellulose and the decrease in the fraction of crystalline cellulose related to the amorphous cellulose - the most suitable form for the subsequent hydrolysis step. In this step, the cellulose undergoes enzymatic hydrolysis in order to obtain glucose that is transformed into ethanol by process microorganisms. Eventually, the sugars released during the hydrolysis of the hemicellulose can be converted into ethanol. Consequently, the involved technologies are more complex leading to higher ethanol production costs compared to that from molasses or starch feedstock.

BENEFITS OF BIOETHANOL

Domestic production and use of ethanol for fuel can decrease dependence on foreign oil, reduce trade deficits (Charles *et al*., 1992), create jobs in rural areas, reduce air pollution, global climate change and carbon dioxide build up (Ofoefule *et al*., 2009) bioethanol, unlike gasoline, is an oxygenated fuel that contains 35% oxygen, which reduces particulate and NOx emissions from combustion (Lang *et al*., 2001).

Ethanol provides energy that is renewable and less carbon intensive than oil. Bioethanol reduces air pollution due to its cleaner emissions and also contributes to mitigate climate change by reducing greenhouse gas emissions (GHG). In comparison to gasoline utilization, reduction of greenhouse gas emissions occurs, since much carbon dioxide is taken up by the growing plants as is produced when the bioethanol is burnt, with a zero theoretical net contribution. Several studies have shown that sugarcane-based ethanol reduces greenhouse gases by 86 to 90% if there is no significant land use change (Isaias *et al*., 2004; Goettemoeller and Goettemoeller, 2007) and ethanol from sugarcane is regarded as the most efficient biofuel currently under commercial production in terms of GHG emission reduction (Rajagopal and Zilberman, 2007).

Since, bioethanol is of plant origin, the carbon dioxide (CO_2) emitted when it is blended with gasoline and burned is not counted as greenhouse gas emissions, it is recaptured as a nutrient to the crops that are used in its production. Bioethanol is appropriate for the mixed fuel in the gasoline engine because of its high octane number. Its low cetane number and high heat of vaporization impede self-ignition in the diesel engine. Since, it is an octane enhancing additive and removes free water which can plug fuel lines in cold climates; ignition improver, glow-plug, surface ignition and pilot injection are applied to promote self-ignition by using diesel-bioethanol-blended fuel (Lang *et al*., 2001). Some countries have already been blending gasoline with bioethanol produced from such materials as sugar cane. In Japan, a blended fuel containing three-percent bioethanol was introduced in fiscal 2004 (Anonymous, 2005).

DISADVANTAGES OF BIOETHANOL

Disadvantages of bioethanol include its lower energy density than gasoline, its corrosiveness, low flame luminosity, lower vapor pressure (making cold starts difficult), miscibility with water and toxicity to ecosystems (Mustafa *et al*., 2008). For ethanol to be currently economically viable, requires massive Government Federal subsidies and price supports. In the USA, even the biggest of proposed ethanol supports-an increase in mandated ethanol consumption from 7.5 billion gallons a year to 15 billion gallons a year, as called for in their energy bill by congress would barely dent America's oil consumption, which is approximately 150 billion gallons annually (Wikipedia, 2007).

Scientists report that ethanol may end up contributing to global warming more than fossil oil, where rainforests are destroyed to produce it. This is also applicable to other biofuels such as biodiesel (Sanchez, 2007). Another concern about ethanol as a gasoline substitute is the fact that only about 5 million automobiles out of 135 million currently in America are Flexible-Fuel Vehicles (FFV)-cars that are equipped to run on a blend of 85% ethanol and 15% gasoline (known as E85).

PROSPECTS OF BIOETHANOL PRODUCTION FROM VARIOUS BIOMASS MATERIALS

The main sources of sugar required to produce ethanol are derived from fuel or energy crops. These crops are grown specifically for energy use and include corn, maize and wheat crops, waste straw, willow and poplar trees, sawdust, reed canary grass, cord grasses, Jerusalem artichoke, miscanthus and sorghum plants, wheat grains and/or straw (Coppola *et al*., 2009). To avoid conflicts between human food use and industrial use of crops, only the wasted crop, which is defined as crop lost in distribution, is considered as efficient feedstock. Bioethanol feedstocks are plants that have high sugar or starch content like sugarcane or corn. It can only use the sugars and starches from the fruit and not from the entire plant. In Europe, the feedstock used for bioethanol is predominantly wheat, sugar beet, corn and wastes from the wine industry. Wheat has proven to be a very good raw material for the bioethanol production and is considered as a primary commodity for the bioethanol production also in Australia (Mojovic *et al*., 2009).

Olive stones (pits): This could be the newest ethanol feedstock used in Spain and could give the olive processing industry an opportunity to turn the 4 million tons of olive stones it generates every year into a valuable asset. This raises the possibility of utilizing olive stones, which would otherwise be wasted, in producing energy. In this way the whole food crop would be utilized. The olive stone, removed when processing raw olives for use as olive oil and table olives, makes up around a quarter

Table 1: Parts of the corn plant

Part	Grams (g)	Total plant (%)
Total plant	736	100.0
Ear which include:	319	43.3
Grain	218	29.6
Cob	58	7.9
Shuck	43	5.8
Leaves	54	7.3
Tassel	3	0.4
Stalk	360	48.9

Source: Willis *et al*. (2009)

of the total fruit. It is rich in polysaccharides (cellulose and hemicellulose) that can be broken down into sugar and then fermented to produce ethanol. Sebastian (2008) reported the conversion of olive stones to ethanol. Olive stones were pre-treated using high-pressure hot water then enzymes that degrade plant matter and generate sugars were added. The hydrolysate obtained from this process was then fermented with yeasts to produce ethanol. Yields of 5.7 kg of ethanol per 100 kg of olive stones have been obtained. The low cost of transporting and transforming olives stones make them attractive for biofuels production (Sebastian, 2008).

Corn: Corn is produced in greater weight each year than any other grain around the world, which makes it suitable for cultivation as a fuel source. Corn utilizes C4 carbon fixation, as opposed to the C3 carbon fixation process of plants like soybeans and smaller grains and as such corn is a more effective carbon source. Each corn plant can be divided into the ear (which includes the grain, cob and shuck), leaves, tassel and stalk (Table 1). Most of these components contain cellulose, a rigid material digested only by fungi and certain species of bacteria and, as at 2006, it was not yet widely profitable to convert cellulose to ethanol for fuel using bacteria and yeast enzymes (Willis *et al*., 2009).

Without the ability to convert cellulose to ethanol profitably, only the grain (about 30% by weight) can be directly utilized. Recently, processers have devised other productive ways to use the discarded cellulosic mass that is not converted to ethanol, such as using it to power their processing plants. Of the 692 million metric tons of corn produced annually around the globe, 280 million metric tons are produced by the United States whose midwest region has ideal seasons, climate and moist soil for growing short-rooted corn (Grassi, 2001).

Sugar cane: Sugar cane also contains parts that can not yet be profitably processed into ethanol. The bagasse is the name given to the biomass that remains from the sugar stalk after it has been crushed and the sugar and garapa (juices) have been extracted. Although, it is not yet commercially converted to ethanol, however research works are on-going to profitably convert the bagasse into ethanol. The bagasse is also useful in the production process. Many sugar mills have utilized the bagasse for cogeneration-both heat and electric energy production-to power the mills. Like other parts of the plant, the bagasse does not add to net atmospheric carbon dioxide, because any carbon dioxide released will be consumed by another cane plant. Bioethanol production from sugarcane was started in Brazil and the United States in the early 1970's (Chatanta *et al*., 2008). Of the 1,324 million metric tons of sugar cane produced annually, Brazil contributes about 420 million (which is by far the greatest contribution of any country in the world). Before the enactment of ethanol fuel, the cane plants were used almost entirely for production of foodstuffs-sugar, molasses and rum. Often in surplus, sugar cane proved to be an ideal source of fuel once it became profitable to mass-produce the ethanol (Grassi, 2001).

Sweet sorghum: Sweet Sorghum is an extraordinarily promising multifunctional crop not only for its high economic value (due to its high sustainable productivity approx 20 to 50 dry t ha^{-1} and to the wide range of its products: grains, sugar, lignocellulosics) but also for its capacity to provide a very wide range of renewable energy products, industrial commodities, food (grains and sugar) including animal feed products. Its low water requirements can be compared with others as ⅓ of sugar cane, ½ of corn, ¼ of short rotation forestry. It is estimated that a biomass yield of 80 fresh t ha^{-1} and a sugar production of approx 7 t ha^{-1} would be possible in the future. The sugar content consists of sucrose, fructose and glucose. Most of the sugar is uniformly distributed in the stalk; only 2% in the leaves and panicle (Grassi, 2001).

The stalks of sweet sorghum harvested just before flowering contain almost as much sugar as sugarcane (16-23% Brix). Besides having wide adaptability, rapid growth and high sugar accumulation and biomass production potential, sweet sorghum, is tolerant to drought, water logging, soil salinity and acidity. Under socio-economic conditions prevailing in India, the cost of ethanol production per liter from sweet sorghum juice is competitive with that of sugar cane molasses and significantly less than with maize grain as feedstock (Reddy *et al*., 2007). Like sugarcane, sweet sorghum bioethanol systems also yield a highly positive net energy balance (Energy output/fossil energy input estimated at approximately 8), roughly four times higher than for maize grain as feedstock in the USA. Sweet sorghum is an excellent source of biomass as it yields 30-35 tones of biomass per ha in 4-5 months. When harvested green it is succulent and rich in cellulose (15-25%) and hemicellulose (35-50%), making it amenable for microbial digestion and fermentation (Reddy *et al*., 2007).

Lignin, the non-sugar structural component ranges from 20-30% in cell wall in sweet sorghum. Brown midrib genotypes have reduced lignin content (up to 50% less), which helps reduce the cost of enzyme requirement for converting cellulose to glucose. International Center for Research in the Semi Arid Tropics (ICRISAT) is focusing on development of photo and thermo-insensitive sweet sorghum hybrid parents with high Brix and brown midrib hybrids to facilitate the bioenergy production using first and second generation ethanol production technology while ensuring the grain yield potential for food security. The stillage (main frame of the plant) obtained after crushing the cane is an excellent animal feed (Reddy *et al*., 2007).

Sweet sorghum can be strongly recommended as a key alcohol crop in Taiwan, because of its short growing period, low water requirement, large amount of biomass and alcohol produced and greater income obtained from sweet sorghum cultivation (Sin-Yie and Chien-Yih, 2009).

Switch grass: A native tall-grass prairie species, switch grass is considered the most promising ethanol production feedstock because of its high yields, low inputs and ability to adapt to a variety of conditions (Johnson, 2009) Ethanol production from switch grass depends on development of cellulosic technology. The annual yield (L ha^{-1}) is between 3100-7600 while its Greenhouse-gas savings (% versus petrol) stands in the range 37-73 (Wikipedia, 2009b). Test plots of switch grass at Auburn University have produced up to 15 t of dry biomass per acre and 5 year yields average of 11.5 t-enough to make 1,150 gallons of ethanol per acre each year (U.S. Department of Energy, 2007). Switch grass grows fast and is remarkably adaptable. Besides showing great promise for energy production, switch grass also restores vital organic nutrients to farmed-out soils. Ethanol from switch grass can produce about five times more energy output than input and about 20 times better than corn if factors such as energy required to make tractors, transport farm equipment, plant and harvest and so on are not considered. Unlike corn, switch grass does not need to be replanted each year. It also takes less tractor fuel and fertilizer to produce. It can be grown on marginal land and does not require as much water (Johnson, 2009).

Cassava: Cassava, a tuber crop which is also known as manioc, sagu, yucca and tapioca is one of the most important tropical root crops with great potentials for bioethanol production. In addition to its ability to survive drought, it does not require a lot of attention and is particularly suitable for regions with low nutrient availability. Cassava is grown worldwide (particularly in Africa, South America and most of Southeast Asia) as a food source for billions of people, raising the possibility that it could be used globally to alleviate dependence on fossil fuels (Hankoua and Besong, 2009).

Africa and Asia lead the world in cassava production. Cassava production in Africa in 2005 was 118 million Metric Tonnes (MT) and accounted for 56% of the total world production, whereas Asia contributed 57 million MT or 27% of total world production. Nigeria is the world's largest cassava producer. Recently cassava has emerged as the primary starch-based feedstock for future fuel ethanol production in Africa and Asia (Drapoch, 2008). Cassava grows in diverse environments, especially extremely harsh climatic conditions and its starch is already being used for large-scale ethanol production in many Asian and African countries.

Cassava contains 20-40% starch and about 70% moisture. However when dry, it contains 73% starch and gives a theoretical ethanol yield of 0.45 L kg^{-1}. Cassava starch can be easily hydrolyzed to sugars for production of fermentation-based products. Cassava starch costs 15-30% less to produce per acre than corn starch making cassava an attractive and strategic source of renewable energy (Hankoua and Besong, 2009).

Sweet potatoes: According to researchers at USDA's Agricultural Research Service who studied the potential to use sweet potatoes as a feedstock for producing ethanol, sweet potatoes produce two to three times as many carbohydrates than corn. Unlike corn, sweet potato and cassava require less fertilizer and pesticide and the yield approaches the lower limit of those produced by sugarcane (Schill, 2008).

Sugar beet: Theoretically a ton of sugar beet will give 110 L ethanol whereas, a ton of barley gives 340 L ethanol. On the other hand, a hectare area of sugar beet gives 4200 L ethanol and 1200 L of ethanol for the barley, respectively (Kymalainen, 2007). Beet sugar can boost ethanol production by adding crystallized sugar to corn slurry- speeding fermentation (Wagner, 2005). Bioethanol has also been produced from sugar beet molasses by calcium (Ca)-alginate immobilized *Saccharomyces cerevisiae* yeast in the presence of castor oil, without heat or filter sterilization (Zayed, 1997). The bioethanol production process can act also on the debris from sugar beet increasing the conversion by an additional 30% by using *Bacillus strearothermophilus* bacterium that digests hemicellulose, a sugar that yeast is unable to break down.

Miscanthus: Miscanthus is low-input perennial grass which grows as tall as 13 feet, requires little or no fertilizer and can be stored away in bales almost indefinitely. According to Dohleman (2007), it has longer growing season, greater leaf area and higher carbon storage per unit of leaf area.

Ethanol production depends on development of cellulosic technology. It has a high annual yield (liters/hectare) of 7300 comparable to that of sugarcane (6800-8000). According to researchers from University of Illinois at Urbana-Champaign, *Miscanthus giganteus*- closely related to switch grass proved in field tests to be significantly more productive than other crops. Its land requirement is less. While corn or switch grass will require 25% of US land to produce enough ethanol to replace one-fifth of US gasoline use, only 9.3% of acreage will be required with miscanthus to produce the same amount of ethanol. Compared with corn or switch grass, miscanthus yields 2.5 times more ethanol feedstock in the same acreage (Oslen, 2008).

Other sources: A supplemental feedstock of whole potatoes, tapioca, potato starch, corn syrup, sugar beets and surplus sugar was necessary for an ethanol plant that was operated with constant flow. Two factories have produced 10 to 15 million liters of fuel grade ethanol per year with a positive cash flow (Mann *et al*., 2002). Feasibility of lignocellulosic materials for ethanol production has been explored around the world depending on availability. At present, the fermentation of sugars to ethanol is the best established process for conversion of biomass to energy (Chatanta *et al*., 2008). Bioethanol is currently commercially produced from raw materials such as sugar cane, sugar beet or starch from cereals. The production of ethanol from low cost lignocellulosic materials such as crop wastes and horticulture wastes has considerable promise as a future source of liquid transport fuel, the pomace left after juice extraction can be used as collected (Chatanta *et al*., 2008). Apple pomace is the residue left after juice extraction and constitutes about 25-35% of the weight of fresh fruit. It contains a large amount of water and sugar, a small amount of protein and has a low pH. More than 500 food processing plants in the United States produce a total of about 1.3 million metric tons of apple pomace per year. Hang *et al*. (1982) have documented the potential for ethanol production from fresh wet pomace and this represents a 20% of energy recovery from the total energy in pomace (Jewell and Cummings, 1984).

Bioethanol production and utilization status in different parts of the world: The global annual potential bioethanol production in the world as a whole are from the major crops such as corn, barley, oat, rice, wheat, sorghum and sugar cane. Lignocellulosic biomass such as crop residues and sugar cane bagasse are included in feedstock for producing bioethanol as well. Asia is the largest potential producer of bioethanol from crop residues and wasted crops and could produce up to 291 GL year^{-1} of bioethanol. Rice straw, wheat straw and corn stover are the most favorable bioethanol feedstocks in Asia. The next highest potential region is Europe (69.2 GL of bioethanol), where most bioethanol comes from wheat straw. Corn stover is the main feedstock in North America, from which about 38.4 GL year^{-1} of bioethanol can potentially be produced. Globally rice straw can produce 205 GL of bioethanol, which is the largest amount from single biomass feedstock. The next highest potential feedstock is wheat straw, which can produce 104 GL of bioethanol (Kim and Dale, 2004).

In 1993 only 60 million litres of bioethanol was produced in Europe compared to a little over 900 million litres the previous year. From 2004 to 2005 there was an increase of almost 70%. This increase can be explained by: (1) higher production in France due to new government support, (2) crisis in distillation measures in the wine sector resulting to a much bigger volume of wine alcohol in the market and (3) growth in Germany because of new production capacity coming on-stream (Miguel, 2006).

EU production in 2005 was around 900 million litres. However, total consumption was close to 1,200 million litres. Sweden, Germany and the UK consumed much more than they produced and are therefore strong import markets while Spain is a strong exporter. Production in Sweden is about 60 million litres home-grown production while the remaining is about 100 million litres of wine alcohol converted to fuel grade ethanol. Traditionally, it was Spain buying the highest volumes, but in 2005 Sweden took over. In comparison with the USA and Brazil, EU ethanol for fuel production is still very modest. The two giants are now in competition for the title of world biggest producer. The European Council had already called for 8% increase in production by 2015. However, it is believed that this target can be surpassed. Minimum targets of 10% by 2015, 15% by 2020 and 25% by 2030 have also been proposed (Miguel, 2006).

In Europe mainly grain (barley, wheat and rye) and some sugar beet have been used for bioethanol production (Enwald, 2007) and in USA, corn (Tavares, 2007). France is a frontrunner in the EU, producing over 800 million liters ethanol from sugar beet and wheat in 2004 (Murray, 2005). Cooperatives have a significant role in sugar-to ethanol plants in the USA (Jacobs, 2006). In the years 2004-2007, local farmers in Häme, in Southern part of Finland, also started to source alternative use for sugar beet due to expected drastic reduction of domestic sugar production in the near future.

Japan, is developing a technology to produce bioethanol from waste paper and other materials by using cellulolytic yeast which is genetically engineered from cellulose.

Production of bioethanol from sugar cane and corn is currently costly; it requires large facilities. In contrast, the technology currently under development uses waste paper that cannot otherwise be recycled, which makes it possible to reduce costs and to use resources effectively. The existing bioethanol manufacturing methods require much time and involve high costs for the processes of fermenting and distilling starch. By using a special kind of bacteria, the new technology can drastically shorten the processes.

Shingoshu was developing the technology, aiming to enter the market in 2007 and is expecting an annual production of 36,500 L of bioethanol by 2012, which would mean an annual reduction of CO_2 emissions by about 51,700 t (Anonymous, 2005).

Asia-Pacific ethanol production is expected to grow tremendously in the coming years and could represent as much as 20% of global ethanol production by 2015 (Johnson, 2009). If India's own projections are realized, it could outpace Brazil in ethanol production and exporting by 2015. Nonetheless, despite India's ethanol production expansion, Hart projects that Brazil will remain the leading global biofuels exporter (Johnson, 2009).

In China, cassava is considered as the alternative starch-based feedstock to replace corn in ethanol production. For instance, The China nation Cereals, Oils and Foodstuffs Corp, (COFCO) has built 17 MMgy Cassava ethanol plant in Beihai, Guangx. This plant operated as Bioenergy Co Ltd is the country's first fuel ethanol plant based on a non-grain feedstock (Austin, 2008). There are also proposals to build several ethanol plants using cassava in other countries such as Nigeria and Thailand. Production of bioethanol at a competitive price with fossil fuel by saccharification and fermentation of lignocellulosic biomass has been achieved through investigation of biomass resources in Asian countries through experimental study for hydrothermal pretreatment, following saccharification and its evaluation. These led to process design for optimum ethanol production. The rationalization of fermentation and pretreatment processes resulted in a new fermentation process based on high speed fermentation method by a high bacteria concentration of 30wt%. The rationalization process enabled the cost reduction by 30% compared to that of the new National Renewable Energy Laboratory (NREL) process (¥29.8/kg-ethanol) (Yamaji *et al.*, 2006).

Table 2: Brazilian ethanol exports by selected country and region (Millions of liters)

Country/Region	2007	Percentage	2006	Percentage	2005	Percentage
United States	932.75	26.4	1,777.43	51.9	270.97	10.5
CBI countries	910.29	25.8	530.55	15.5	554.15	21.4
Jamaica	308.97		131.54		133.39	
El Salvador	224.40		181.14		157.85	
Costa Rica	170.37		91.26		126.69	
Trinidad and Tobago	158.87		71.58		36.12	
Mexico	42.21		50.24		100.10	
European Union	1,004.17	28.4	587.31	17.1	530.73	20.5
Netherlands	808.56		346.61		259.40	
Sweden	116.47		204.61		245.89	
Japan	364.00	10.3	225.40	6.6	315.39	12.2
Niger	122.88		42.68		118.44	
Republic of Korea	66.69		92.27		216.36	
India	0		10.07		410.76	15.8
Total world exports	3,532.67	100	3,426.86	100	2,592.29	100

Source: Sanchez (2007), Exportacoes Brasileira de Alcool (2008a), The World Bank (2008), Ribeiro (2008), Exportacoes Brasileira de Alcool (2008b), Exportacoes Brasileira de Alcool (2008c)

Table 3: Brazilian ethanol production [(a)] in Millions of U.S. gallons

Year	Production
2004	3,989
2005	4,227
2006	4,491
2007[(b)]	5,019
2008[(b)]	6,472

Source: Renewable Fuels Association (2009). [(a)]Ethanol all grades. [(b)]2007 is for ethanol fuel only

Brazil is the world's second largest producer of ethanol fuel and the world's largest exporter. As shown in Table 2, Brazil in 2007 exported 933.4 million gallons (3,532.7 million liters), representing almost 20% of its production and accounting for almost 50% of the global exports. Since 2004, Brazilian exporters have as their main customers the United States, Netherlands, Japan, Sweden, Jamaica, El Salvador, Costa Rica, Trinidad and Tobago, Nigeria, Mexico, India and South Korea (Sanchez, 2007). Together, Brazil and the United States lead the industrial production of ethanol fuel, accounting together for 89% of the world's production in 2008. Table 3 shows Brazilian ethanol production in Millions of U.S. gallons. In 2008, Brazil produced 24.5 billion litres (6.47 billion US liquid gallons), which represents 37.3% of the world's total ethanol used as fuel (The World Bank, 2008; Renewable Fuels Association, 2009).

Ethanol production in Brazil using sugarcane as feedstock relies on first-generation technologies based on the use of the sucrose content of sugarcane. Ethanol yield has grown by 3.77% per year since 1975 and productivity gains have been based on improvements in the agricultural and industrial phases of the production process. Further improvements on best practices are expected to allow (in the short to mid-term) an average ethanol productivity of 9,000 L ha^{-1} (Goldemberg, 2008). There were 378 ethanol plants operating in Brazil by July 2008; 126 dedicated to ethanol production and 252 producing both sugar and ethanol. There are 15 additional plants dedicated exclusively to sugar production (Goldemberg, 2008). These plants have installed capacity of crushing 538 million metric tons of sugarcane per year and there are

25 plants under construction expected to be on-line by 2009, that will add an additional capacity of crushing 50 million tons of sugarcane per year. The typical plant costs approximately USD 150 million and requires a nearby sugarcane plantation of 30,000 ha (Empresa de Pesquisa Energetica, 2008).

Ethanol Africa has established a programme to secure crops for bio-ethanol production whereby farmers would be financed by the company to produce maize. Ethanol Africa alleges its manufacturing initiative could supply up to 12.5% of South Africa's fuel needs by 2015 (Ethanol Africa, 2006). In the US, corn ethanol which is ethanol produced from corn as a biomass through industrial fermentation, chemical processing and distillation is primarily used as an alternative to gasoline and petroleum (first-generation biofuel). Corn ethanol is the most common type of ethanol in the United States, but is considered less efficient than other types of ethanol (sugar cane, etc.) because only the grain is used and many petroleum-based products (fertilizer, pesticides, etc) are used in its production. According to a report by the National Renewable Energy Laboratory (NREL), Over 80% of US ethanol is produced from corn by the dry grind process (Anonymous, 2006). However efforts to develop the use of other agricultural products such as cassava, sugar beets, sweet sorghum, sweet potatoes, etc., are underway. The US Department of Energy (DOE) has set the goal of making cellulosic ethanol cost competitive by 2012 and by 2030, it aims to make biofuels displace 30% of that country's projected gasoline use (Johnson, 2009). Some of the feedstock being considered to meet these goals are crop residues, perennial woody crops and perennial grass. The United State Department of Agriculture (USDA) provided loan of up to $ 250 million dollars for research into renewable fuels and recently it has awarded loan to Range fuels to build a 100 million gallons cellulosic ethanol plant in Georgia using mostly woods and forest residues (Mukesh, 2009).

The biomass energy resource base of Nigeria is estimated to be about 144 million tones per year. Nigeria's land area is about 79.4 million hectares of which 71.9 million hectares can be considered to be arable. This shows a huge potential for the production of biomass since an estimated 94% of Nigeria's household are engaged in crop farming. Nigeria's aggregate annual crop production of 93.3 million tonnes of major crop yields far more quantity of straws, chaff, leaves and other biomass materials. This expanse of arable land holds promise for cropping of energy crops especially for bioethanol production. Some of the identified energy crops are not edible and as such cannot affect the food chain (ECN, 2009).

In Nigeria, ethanol production for transportation is still at the research and developmental stage. They are yet to be commercially produced in the country though serious efforts are in progress to get the technology commercialized. Some private concerns have also indicated plans to commence cultivation of some energy crops for the production of bioethanol in some parts of the country (Sambo, 2007). Some of the research and developmental works in bioethanol are also already being focused on using feedstock that are either not edible, are wastes or are not widely consumed to reduce competition with food. This is expected to reduce concerns on food security and they include; Ethanol production from a three leaved yam (*Dioscorea demetorium*) an alternative source of fuel or fuel extender (Garba *et al*., 1997). Evaluation of ethanol production from enzymatically hydrolyzed S*accharin officinarum* bagasse (Udotong, 1997). The pilot plant designed to produce 100 litres per day of fuel grade ethanol from sugar cane was carried out, test run and eventually commissioned by the Kaduna State Government of Nigeria (Ofoefule *et al*., 2008). These are also in addition to other research works going on in the area of bioethanol using other local sources such as cassava. Nigeria is actually the world's largest cassava producer (Drapoch, 2008).

CONCLUSION

When ethanol fuel is produced from lignocellulosic materials such as wood, herbaceous plants, wild tubers, agricultural and forestry wastes, its use as a transportation fuel reduces dependence on imported petroleum, decreases the balance of trade deficit, improves urban air quality, contributes no net carbon dioxide to the atmosphere and provides new markets for depressed farm economies. The simultaneous saccharification and fermentation (SSF) process is a favoured option for conversion of the lignocellulosic biomass into ethanol because it provides enhanced rates, yields and concentrations of ethanol with less capital investment compared to competing processes. Agricultural crop residues such as corn stover, wheat and rice straw residues generated from citrus processing, coconut biomass, grasses and residues from the pulp and paper industry (paper mill sludge), as well as municipal cellulosic solid wastes, will eventually be also used as raw materials to produce ethanol. Although each source of biomass represents a technological challenge, the diversity of raw materials will allow the decentralization of fuel production with geopolitical, economical and social benefits.

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