

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



A Real Story of Bioethanol from Biomass: Malaysia Perspective

K.L. Chin and P.S. H'ng

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/51198>

1. Introduction

Rising fossil fuel prices associated with growing demand for energy, and environment concerns are the key factors driving strong interest in renewable energy sources, particular in biofuel. Biofuel refers to any type of fuel whose energy is derived from plant materials. Biofuel which includes solid biomass, liquid fuels and various biogases is among the most rapidly growing renewable energy technologies in recently. Biofuels are commonly divided into two groups based on the technology maturity which using the terms “conventional” and “advanced” for classification. Conventional biofuel technologies include well-established processes that are already producing biofuels on a commercial scale. These biofuels, commonly referred to as first-generation, include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion. First generation biofuel processes are useful but limited in most cases: there is a threshold above which they cannot produce enough biofuel without threatening food supplies and biodiversity. Whereas, advanced biofuel technologies are extensions from conventional technologies which some are still in the research and development (R&D), pilot or demonstration phase and they are commonly referred to as second- or third-generation. This category includes hydrotreated vegetable oil (HVO), which is based on animal fat and plant oil, as well as bioethanol based on lignocellulosic biomass, such as cellulosic-ethanol. Although there are wide varieties of advanced biofuels conversion technologies exists today, but they are not commercially available yet. Nevertheless, the most commercializable technology and most used biofuel on the global market is bioethanol.

2. Bioethanol

Bioethanol is chemically known as ethyl alcohol (C_2H_5OH) and produced from fermentation of fermentable sugars (i.e. glucose, sucrose, etc.) from plant sources using micro-organisms

(yeasts or bacteria). Bioethanol is a clear colourless liquid, it is biodegradable, low in toxicity and causes little environmental pollution if spilt. In the 1970s, Brazil and the United States (US) started mass production of bioethanol grown from sugarcane and corn respectively. Current interest in bioethanol lies in production derived from lignocellulosic biomass. The most common usage of bioethanol is to power automobiles through mixed with petrol. It can be combined with gasoline in any concentration up to pure ethanol (E100). Anhydrous ethanol, that is, ethanol with at most 1% water, can be blended with gasoline in varying quantities to reduce consumption of petroleum fuels and in attempts reduce air pollution. Bioethanol burns to produce carbon dioxide (CO₂) and water. In addition to that, the use of bioethanol is generally CO₂ neutral. This is achieved because in the growing phase of the plant sources, CO₂ is absorbed by the plant and oxygen is released in the same volume that CO₂ is produced in the combustion of the fuel. This creates an obvious advantage over fossil fuels which only emit CO₂ as well as other poisonous emissions [1].

Blending bioethanol with gasoline help to reduce green house gases (GHG) emissions by oxygenate the fuel mixture so it burns more completely. On a life cycle basis, ethanol produced from corn results in about a 20 percent reduction in GHG emissions relative to gasoline. With improved efficiency and use of renewable energy, this reduction could be as much as 52 percent. In near future, bioethanol produced from cellulose has the potential to cut life cycle GHG emissions by up to 86 percent relative to gasoline as reported in EPA's Emission Facts [2].

3. Bioethanol in use

About 75% of bioethanol produced in the world being used to power automobiles, though it may be used for gasoline additives and other industries such as paints and cosmetics. Ethanol fuel blends are widely sold in the United States, Brazil, Europe and China. The most common blend is 10% ethanol and 90% petrol (E10). Vehicle engines require no modifications to run on E10 and vehicle warranties are unaffected also. However, only flexible fuel vehicles can run on up to 85% ethanol and 15% petrol blends (E85). Since 1976 the Brazilian government has made it mandatory to blend ethanol with gasoline with 5% ethanol and 95% petrol, and in 2007 the legal blend is around 25% ethanol and 75% gasoline (E25). Today, bioethanol contribute around 3% of total road transport fuel globally (on an energy basis) and considerably higher shares are achieved in certain countries [3]. The usage of bioethanol as transport fuel will be even more as the recent European Commission energy roadmap has set a target to increase the use of biofuels for transport from 5.75% from 2010 to 10% by 2020 under the Directive 2003/30/EC.

Bioethanol is also used as primarily gasoline additive and extender due to its high-octane rating. Bioethanol replacing lead as an oxygenate additive for traditional petrols in the form of Ethyl tertiary butyl ether (ETBE). The ethanol is mixed with isobutene (a non-renewable petroleum derivative) to form ETBE. At a 10% mixture, ethanol reduces the likelihood of engine knock, by raising the octane rating.

Beside the usage of bioethanol in fuel industry, bioethanol also can serve a wide range of uses in the pharmaceuticals, cosmetics, beverages and medical sectors as well as for industrial uses. The market potential for bioethanol is therefore not just limited to transport fuel or energy production but has potential to supply the existing chemicals industry. These include for use in acetaldehyde (raw material for other chemicals e.g. binding agent for paints and dyes), acetic acid (raw material for plastics, bleaching agent, preservation), ethylacetate (paints, dyes, plastics, and rubber), detergents, thermol (cold medium for refrigeration units and heat pumps), solvent for spirits industry, cosmetics, print colours and varnish, isopropyl alcohol (IPA), ethyl acetate (EAC), WABCO-antifreeze (disinfectant, cleaning agent for electronic devices, solvents) and vinasse, potassium sulphate (feeding stuffs, fertilizer).

4. Bioethanol technology

Bioethanol can be produced either from conventional or advance biofuel technologies depending on the state of sugars polymerization. The predominant technology for producing bioethanol is through fermentation of sucrose from sugar crops such as sugarcane, sugar beet and sweet sorghum. Bioethanol produced from sugar or starchy materials is categorized under the conventional technology and the bioethanol so called first generation bioethanol. Whereas, at present, much focus is on the bioethanol produced from biomass that possesses lignocellulosic content. This second generation bioethanol or cellulosic ethanol could be produced from abundant low-value material, including wood chips, grasses, crop residues, and municipal waste.

Regardless of the bioethanol technologies used to produce bioethanol, the bioethanol process have to undergo several treatment steps in which normally involves pre-treatment, extraction of fermentable sugars and fermentation. Pre-treatment process mainly deals with the preparation of the feedstock into smaller size (higher surface to volume ratio) for ease of sugars extraction. Whereas, extraction process with the aim of transforming the various sugars polymer chains into simple fermentable sugars. Fermentation process is a biological process in which fermentable sugars are converted into cellular energy and thereby produce ethanol and carbon dioxide as metabolic waste products in the absence of oxygen (anaerobic process) using *Saccharomyces cerevisiae*. The theoretical yield of bioethanol is 0.51 g per one gram of glucose consumed during fermentation.

5. Bioethanol conversion yield

Commercial production of bioethanol deals with the biotechnological production from different feedstock. The selection of the most appropriate feedstock for ethanol production strongly depends on the local conditions. Due to the agro-ecological conditions, North American and European countries have based their ethanol industry on the starchy materials. In Brazil, sugarcane is the main feedstock for bioethanol production. World production of ethanol (all grades) in 2010 was nearly 70 billion litres (IEA, 2010). Although many countries produce ethanol from a variety of feedstocks, Brazil and the United States

are the major producers of ethanol in the world, each accounting for approximately 35 percent of global production [4].

The theoretical yield of ethanol from sucrose is 163 gallons of ethanol per tonne of sucrose. Factoring in maximum obtainable yield and realistic plant operations, the expected actual recovery would be about 141 gallons per tonne of sucrose [5]. Using [6],[7] and [8] reports, average sugar recovery rates, one tonne of sugarcane would be expected to yield 70 L of ethanol and one tonne of sugar beets would be expected to yield 100 L of ethanol. One tonne of molasses, a byproduct of sugarcane and sugar beet processing, would yield about 260 L of ethanol. Corn had the highest ethanol yield per tonne feedstock (403 L/t), followed by wheat with 350 L/t [9]. A lower ethanol yield per tonne of feedstock was obtained for cassava compared to corn. The ethanol yield from starchy materials were basically higher than sugar containing material because of the higher amount of fermentable sugars (glucose) that may be released from the original starchy material [10].

The conversion of sugar containing material into bioethanol is easier compared to starchy materials and lignocellulosic biomass because previous hydrolysis of the feedstock is not required since this disaccharide can be broken down directly by the yeast cells [11]. Therefore, using raw sugar as a feedstock, one tonne would yield 500 L of ethanol while refined sugar would yield 530 L ethanol. Molasses, from either sugarcane or sugar beets, was found to be the most cost competitive feedstock. The table below summarizes the estimated ethanol production yield and conversion efficiency from starchy and sugar containing materials from all over the world, as well as research ethanol yield produced from lignocellulosic biomasses.

Bioethanol is currently produced from raw materials such as sugar cane, or beet or starch from cereals. Recent interest was on the low cost and abundant availability of lignocellulosic biomass as the potential feedstock for bioethanol production. Lignocellulosic biomass which includes agricultural and forestry residues and waste materials, has the advantage of providing a greater choice of potential feedstock that does not conflict with land-use for food production, and that will be cheaper than conventional bioethanol sources. Many researchers from around the world are now working on transforming lignocellulosic biomass such as straw, and other plant wastes, into "green" gold - cellulosic ethanol. Cellulosic ethanol, a fuel produced from the stalks and stems of plants (rather than only from sugars and starches, as with corn ethanol), is starting to take root in the United States.

The bioconversion of lignocellulosic biomass to monomeric sugars is harder to accomplish than the conversion of starch, presently used for bioethanol production. However, many countries are making efforts to utilize these lignocellulosic biomasses into ethanol; Sweden, Australia, Canada and Japan are planning to invest into lignocellulosic ethanol mill [21]. The highest ethanol yield from lignocellulosic materials was obtained using switchgrass, 201 L/t with 80% conversion efficiency. Ballesteros *et. al* [20] studied on ethanol conversion using woody material such as *Populus nigra* and *Eucalyptus globule* found that the yield of 145 L/t and 137 L/t feedstock and conversion efficiency ranging 59% - 64% was observed. The conversion efficiency for lignocellulosic materials was lower than the conversion efficiency obtained from sugar-containing material and starchy material.

Feedstock		Sugar convertible materials (%)	EtOH yield (L/t)		Conversion efficiency (%)	Source
			Actual ethanol yield	Theoretical ethanol yield		
Sugar containing materials	Sugar cane juice(80% MC)	12	70	78	90	[6]; [7]
	Sugar beet (75% MC)	18	100	116	86	[8]
Starchy materials	Cassava (40% MC)	32	178	207	86	[12]
	Sweet sorghum (14% MC)	15	80	97	82	[13]
	Wheat (14% MC)	66	350	427	82	[14]
	Corn (15% MC)	70	403	452	89	[15]
Lignocellulosic biomass*	Cane bagasse	33	140	213	66	[16]
	Wheat straw	36	140	233	60	[17]
	Corn stalk	35	130	226	63	[18]
	Switchgrass	39	201	252	80	[19]
	<i>Populus nigra</i>	35	151	226	64	[20]
	<i>Eucalyptus globulus</i>	36	138	232	59	[20]
	<i>Brassica carinata</i>	33	128	213	60	[20]

* Note: Sugar convertible materials are referred as cellulose content.

Table 1. Comparative indexes for three main types of bioethanol feedstocks

The selection of the feedstock is in concordance with the interests of each country based on their availability and low cost. Because feedstocks typically account for greater than one-third of the production costs, maximizing the bioethanol yield is imperative [22].

6. Bioethanol from lignocellulosic biomass

Second generation bioethanol which made from lignocellulosic biomass or woody crops, agricultural residues or waste is considered a future replacement for the food crops that are currently used as feedstock for bioethanol production. Technology for producing bioethanol from biomass is moving out of the laboratory and into the commercial place. Breakthroughs in bioethanol technology in the past decade has lead to commercialization of biomass conversion technology. In U.S alone, Six companies were listed by the U.S Environmental

Protection Agency (EPA) as cellulosic ethanol producers, and their combined anticipated production volume is 8 million ethanol-equivalent gallons for coming years [23]. The six companies are DuPont Danisco Cellulosic Ethanol LLC, Fiberight LLC, Fulcrum Bioenergy Inc., Ineos Bio, KL Energy Corp. and ZeaChem Inc. In April 2011, Mossi & Ghisolfi Group (M&G) (Chemtex) commenced construction of a commercial-scale 13 million gallons/year (50 million liters) cellulosic ethanol production facility in Crescentino, Italy. Beside that, there is Abengoa Company, which has a 5m litre/year demonstration plant at Salamanca, Spain. In October 2010, Norway-based cellulosic ethanol technology developer Weyland commenced production at its 200,000 liter (approximately 53,000 gallon) pilot-scale facility in Bergen, Norway. In Asia, Nippon Oil Corporation and other Japanese manufacturers including Toyota Motor Corporation plan to set up a research body to develop cellulose-derived biofuels. The consortium plans to produce 250,000 kilolitres (1.6 million barrels) per year of bioethanol by March 2014. In China, cellulosic ethanol plant engineered by SunOpta Inc. and owned and operated by China Resources Alcohol Corporation that is currently producing cellulosic ethanol from corn stover (stalks and leaves) on a continuous, 24-hour per day basis.

6.1. Process

Various process configurations are possible for the production of bioethanol from lignocellulosic biomass, the most common method for bioethanol conversion technology from lignocellulosic biomass involves three key steps:

Pre-treatment : During biomass pre-treatment lignocellulosic biomass is pre-treated with acids or enzymes in order to reduce the size of the feedstock and to open up the plant structure. Normally, the structure of cellulosic biomass is altered; lignin seal is broken, hemicelluloses is reduced to sugar monomers, and cellulose is made more accessible to the hydrolysis that convert the carbohydrates polymers into fermentable sugars.

Hydrolysis: This is a chemical reaction that releases sugars, which are normally linked together in complex chains. In early biomass conversion processes, acids were used to accomplish this. Recent research has focused on enzyme catalysts called “cellulases” that can attack these chains more efficiently, leading to very high yields of fermentable sugars. Although the decomposition of the material into fermentable sugars is more complicated, the fermentation process step is basically identical for bioethanol from either food crops or lignocellulosic biomass.

Fermentation : Microorganisms that ferment sugars to ethanol include yeasts and bacteria. Research has focused on expanding the range and efficiency of the organisms used to convert sugar to ethanol.

6.1.1. Pre-treatment

The aim of the pretreatment is to break down the lignin structure and disrupt the crystalline structure of cellulose for enhancing acid or enzymes accessibility to the cellulose during

hydrolysis step [24],[25]. Lignocellulosic biomass consists of three major components; Cellulose, hemicellulose and lignin and are in the form of highly complex lignocellulosic matrix. Depending on type of lignocellulosic biomass, the lignin content varies from about 10 – 25%, the hemicelluloses content from about 20 – 35% and the cellulose content from about 35 – 50%. Lignin is a polymer of phenyl propanoid units interlinked through a variety of non-hydrolysable C - C and C-O-C bonds. It therefore is a complex molecule with no clear chemical definition as its structure varies with plant species. Hemicellulose is an amorphous heterogenous group of branched polysaccharides. Its structure is characterised by a long linear backbone of one repeating sugar type with short branched side chains composed of acetate and sugars. Cellulose is a linear molecule consisting of repeating cellobiose units held together by Beta- glycosidic linkages. Cellulose is more homogeneous than hemicellulose but is also highly crystalline and highly resistant to depolymerisation. The three components of lignin, hemicellulose and cellulose are tightly bound to each other in the biomass. In fact hemicellulose acts as a bonding agent between cellulose and lignin. In order to convert this biomass to fuel ethanol, the biomass has to be broken up into the individual components first before the molecular chains within each component can be broken up further into simpler molecules.

6.1.2. Hydrolysis

Once the celluloses disconnect from the lignin, acid or enzymes will be used to hydrolyze the newly freed celluloses into simple monosaccharides (mainly glucose). There are three principle methods of extracting sugars from sugars. These are concentrated acid hydrolysis, dilute acid hydrolysis and enzymatic hydrolysis.

6.1.2.1. Concentrated acid hydrolysis process

The primary advantage of the concentrated acid process is the potential for high sugar recovery efficiency [18]. It has been reported that a glucose yield of 72-82% can be achieved from mixed wood chips using such a concentrated acid hydrolysis process [26]. In general, concentrated acid hydrolysis is much more effective than dilute acid hydrolysis [27]. Furthermore, the concentrated-acid processes can operate at low temperature (e.g. 40°C), which is a clear advantage compared to dilute acid processes. However, the concentration of acid used is very high in this method (e.g. 30-70%), and dilution and heating of the concentrated acid during the hydrolysis process make it extremely corrosive. Therefore, the process requires either expensive alloys or specialized non-metallic constructions, such as ceramic or carbon-brick lining. The acid recovery is an energy-demanding process.

Despite the disadvantages, the concentrated acid process is still of interest. The concentrated acid process offers more potential for cost reductions than the dilute sulfuric acid process [28]. The concentrated acid hydrolysis process works by adding 70-77% sulfuric acid to the pre-treated lignocellulosic biomass. The acid is added in the ratio of 1.25 to 1.5 acid to 1 lignocellulosic biomass and the temperature is controlled at 40-60°C. Water is then added to dilute the acid to 20-30% and the mixture is again heated to 100°C for 1 hour. The gel produced from this mixture is then pressed to release an acid sugar mixture. The acid is then

recovered partly by anion membranes and partly in the form of H₂S from anaerobic waste water treatment. The process was claimed to have a low overall cost for the ethanol produced [29].

6.1.2.2. Dilute acid hydrolysis

Dilute acid hydrolysis process is similar to the concentrated acid hydrolysis except using very low concentration of sulfuric acid at higher cooking temperature. Biomass is treated with dilute acid at relatively mild conditions which the hemicellulose fraction is hydrolyzed and normally higher temperature is carried out for depolymerisation of cellulose into glucose. The highest yield of hemicellulose derived sugars were found at a temperature of 190°C, and a reaction time of 5 – 10 min, whereas in second stage hydrolysis considerably higher temperature (230 °C) was found for hydrolysis of cellulose [30].

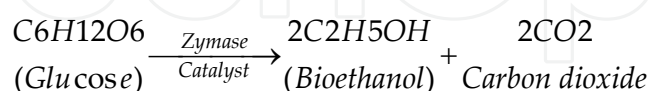
6.1.2.3. Enzymatic hydrolysis

The enzymatic hydrolysis reaction is carried out by means of enzymes that act as catalysts to break the glycosidic bonds. Instead of using acid to hydrolyse the freed cellulose into glucose, enzymes are used to break down the cellulose in a similar way. Bacteria and fungi are the good sources of cellulases, hemicellulases that could be used for the hydrolysis of pretreated lignocellulosics. The enzymatic cocktails are usually mixtures of several hydrolytic enzymes comprising of cellulases, xylanases, hemicellulases and mannanases.

6.1.3. Fermentation process

The hydrolysis process breaks down the cellulosic part of the biomass into glucose solutions that can then be fermented into bioethanol. Yeast *Saccharomyces cerevisiae* is added to the solution, which is then heated at 32°C. The yeast contains an enzyme called zymase, which acts as a catalyst and helps to convert the glucose into bioethanol and carbon dioxide. Fermentation can be performed as a batch, fed batch or continuous process. For batch process, the fermentation process might take around three days to complete. The choice of most suitable process will depend upon the kinetic properties of microorganisms and type of lignocellulosic hydrolysate in addition to process economics aspects.

The chemical reaction is shown below:



6.2. Current development in cellulosic bioethanol

At present, much focus is on the development of methods to produce higher recovery yield bioethanol from lignocellulosic biomass. This can be done through two methods; (1) use of pre-treatment to increase the readiness of lignocellulosic biomass for hydrolysis. (2) increase the conversion yield of lignocellulosic biomass into bioethanol through simultaneous fermentation of glucose and xylose into bioethanol.

As mentioned, one barrier to the production of bioethanol from biomass is that the sugars necessary for fermentation are trapped inside the lignocellulosic biomass. Lignocellulosic biomass has evolved to resist degradation and to confer hydrolytic stability and structural robustness to the cell walls of the plants. This robustness is attributable to the crosslinking between the polysaccharides (cellulose and hemicellulose) and the lignin via ester and ether linkages. Ester linkages arise between oxidized sugars, the uronic acids, and the phenols and phenylpropanols functionalities of the lignin. The cellulose fraction can be only hydrolysed to glucose after a pre-treatment aiming at hydrolytic cleavage of its partially crystalline structure. A number of pre-treatment methods are now available – steam explosion, dilute acid pre-treatment [31] and hydrothermal treatment [32]. Hydrothermal treatment prevent the degradation of cellulose content inside the lignocellulosic biomass during pre-treatment because hydrothermal can be performed without addition of chemicals and oxygen to the lignocellulosic biomass. Hydrothermal treatment involves two process where during the first process, lignocellulosic biomass was soaked in water at 80 °C to soften it before being treated in the second process with higher temperature at 190–200°C.

Another way to increase the recovery yield of bioethanol from lignocellulosic biomass is to convert every bit of biomass into bioethanol. This means using all the available sugars from cellulose and hemicellulose and fermented into bioethanol. Lignocellulosic biomass have high percentage of pentoses in the hemicellulose, such as xylose, or wood sugar, arabinose, mannose, glucose and galactose with majority sugar in hemicelluloses is xylose which account more than 90% present. Unlike glucose, xylose is difficult to ferment. This meant that as much as 25% of the sugars in biomass were out of bounds as far as ethanol production was concerned. At the moment, research shows that steam explosion or mild acid treatment performed under adequate temperature and time of incubation, render soluble the biomass hemicellulose part with the formation of oligomers and C5 sugars that are easily extracted from the biomass. The C5 sugar stream can be individually fermented to ethanol by microorganisms such as *E.coli*, *Pichia stipitis* and *Pachysolen*, that are able to metabolise xylose, or be used as carbon source in a variety of other fermentative processes [33].

7. Bioethanol from lignocellulosic biomass - Malaysia perspective

Malaysia formulated the National Biofuel Policy with envisions to put the biofuel as one of the five energy sources for Malaysia, enhancing the nation's prosperity and well being. This is in line with nation's Five-Fuel Diversification Policy, a national policy to promote renewable energy (RE) as the fifth fuel along with fossil fuels and hydropower. The National Biofuel Policy was implemented in March 2006 to encourage the production of Biofuels, particularly biodiesel from palm oil, for local use and for export. However, in 2007, the Government has announced that the implementation of the whole biodiesel project has been put on hold indefinitely owing to the current high price of refined, bleached and deodorized palm olein.

Recently, the Government of Malaysia launched new strategy to promote the biofuel through the National Biomass Strategy 2020 on year 2011. The aim of National Biomass

Strategy 2020 is to create higher value-added biomass economic activities that contribute towards Malaysia's gross national income (GNI) and creating high value jobs for the benefit of Malaysians. This Strategy outline the production of bioethanol produced from lignocellulosic biomass particularly the oil palm biomass as a starting point with extended to include biomass from other sources such as wood waste. The palm oil sector correspondingly generates the largest amount of biomass, around 80 million dry tonnes in 2010. This is expected to increase to about 100 million dry tonnes by 2020, primarily driven by increases in plantation area. A conservative estimation of utilising an addition 20 million tonnes of oil palm biomass for bioethanol has the potential to contribute significantly to the nation's economy while at the same time reduce the green house gasses emission.

The National Biomass Strategy 2020 proposes a mandate of bioethanol blending of 10 percent in petrol fuel in Malaysia by 2020 to cut down the green house gasses emissions. This would generate a domestic demand for one million tonnes of bioethanol per annum with the first bioethanol from lignocellulosic biomass plant is expected to be commercially viable between 2013 and 2015 [34]. As a result, much attention has been focuses on generating bioethanol from oil palm biomass and wood waste.

As mentioned early, bioethanol utilization as automobile fuel is especially promising as the United States, Brazil and Europe has introduced. However, low-cost supply associated with high bioethanol yield of the bioethanol is indispensable for its wide use. The discussion of economic feasibility of bioethanol production from lignocellulosic biomass in Malaysia in this paper was based on the experimental data through laboratory worked done by [35] and [36] and comparison was made with sugarcane and corn.

7.1. Experiment data

Optimum cellulose conversion to glucose with the hydrolysis efficiency of 82%, 67% and 66% for oil palm trunk, rubberwood and mixed hardwood, respectively obtained using two-stage concentrated sulfuric acid hydrolysis at elevated temperature using 60% sulfuric acid treated in a water bath with a temperature of 60°C for 30 min at the first stage hydrolysis and subsequently subjected to 30% sulfuric acid at 80°C for 60 min at the second stage [36]. As stated in the study by [35], optimum fermentation parameters for lignocellulosic hydrolysates using *Saccharomyces cerevisiae* was obtained using 33.2°C and pH 5.3 with the fermentation efficiency of 80%, 85% and 90% for oil palm trunk, rubberwood and mixed hardwood, respectively. The optimum cellulose conversion and fermentation efficiency were used to calculate the actual ethanol yield per tonne (L/t) and the conversion efficiency of lignocellulosic biomass. The conversion efficiency was calculated in percentage of actual yield over the theoretical yield. The theoretical yield was calculated in assumptions that all the cellulose was converted to glucose and further converted to ethanol theoretical yield (51%) in 100% conversion rate. Using the cellulose conversion and fermentation efficiencies, the actual ethanol yields per tonne lignocellulosic biomass can be calculated for lignocellulosic biomass as the equation below:

$$\text{Ethanol yield in liter per tonne of feedstock (L/t)} = \frac{[1000 \text{ (kg)} \times \text{cellulose content} \times \text{actual hydrolysis efficiency} \times \text{ethanol theoretical yield (0.51)} \times \text{actual fermentation efficiency}] / 0.789}$$

(Note: Ethanol has a density of 0.789 kg/L)

The results of bioethanol yield per tonne for oil palm trunk, rubberwood and mixed hardwood and their conversion efficiencies were presented in Table 2.

	Oil palm trunk	Rubberwood	Mixed hardwood
Celulose content	0.48	0.56	0.56
Hydrolysis efficiency	0.82	0.67	0.66
Ethanol theoretical yield at 100% fermentation efficiency	0.51	0.51	0.51
Actual fermentation efficiency	0.80	0.85	0.90
Actual Ethanol Yield/tonne of dried raw materials	204 L	206 L	215 L
Theoretical Ethanol Yield/tonne of dried raw materials	310 L	362 L	361 L
Total Ethanol Conversion efficiency	66%	57%	60%

Table 2. Ethanol Yield Per Tonne of Feedstock And The Ethanol Conversion Efficiency

As shown from the Table 2, using the same amount of feedstock, mixed hardwood produced slightly higher in volume of bioethanol (215 L/t) compared to oil palm trunk and rubberwood with the ethanol yield per tonne of 204 L/t and 206L/t, respectively. The volume of bioethanol produced using oil palm trunk, rubberwood and mixed hardwood per metric tones of dry weight basically were higher than those reported by [20] as shown in Table 1. The highest conversion efficiency was obtained from oil palm trunk (66%), followed by mixed hardwood (60%) and rubberwood (57%).

If bioethanol yield per tonne feedstock values are taken into consideration, the three lignocellulosic biomass studied was higher than most of the comparing feedstock. The

three lignocellulosic biomass ethanol yields per tonne of feedstock were much higher than sugarcane, sugarbeet and cassava. This could be explained by the high moisture content of the sugarcane, sugarbeet and cassava implies the use of a greater amount of feedstock to reach the same sugar content that may be released from the lignocellulosic material. However, lower bioethanol yield per tonne feedstock of the studied lignocellulosic biomass was found to be lower than those wheat and corn feedstocks. This is due to the higher glucose convertible substance in the wheat and corn which contributed to higher ethanol yield. Overall, the conversion efficiency for the studied lignocellulosic biomass was lower than sugar containing material and starchy material. This showed how critical the hydrolysis and fermentation efficiency of the lignocellulosic biomass contributed to a higher ethanol yield to make it comparable with these commercial feedstocks. The three lignocellulosic biomass used in this study in terms of ethanol yield per tonne feedstock were found to be comparable with the results obtained from the lignocellulosic biomass obtained from other studies and conversion efficiency (Table 1). The studied lignocellulosic biomass contained higher amount of cellulose as the glucose convertible material. Therefore, this may contribute to higher ethanol yield per tonne of feedstock.

7.2. Economic feasibility of bioethanol

The cost of bioethanol per litre presented here mainly calculated from the cost of raw materials used; i.e. lignocellulosic biomass and sulfuric acid and processing cost. Fixed operating costs are excluded from this calculation. Fixed operating costs including labour and various overhead items are fully incurred regardless of the operating production capacity and their contribution to the total cost of bioethanol is estimated at 15 to 18%. [37] stated that cost of biomass contribute almost 60% to the total production cost which is the highest contributor to the cost of bioethanol. Therefore, the main focus here is to estimate the effect of raw materials price on the cost of bioethanol.

7.2.1. Cost of lignocellulosic biomass

Assessing the various costs of mobilising lignocellulosic biomass today which include harvesting, collection, pre-processing, substitution and transportation to a downstream hub, the order of biomass can be mobilised at globally competitive costs, i.e., at a cost of less than RM 250 per dry-weight tonne. The distance of transportation should be less than 100km in radius from the collection area.

7.2.2. Cost of sulfuric acid and recovery charge

The sulfuric acid is sold at RM 264 per tonne. By far, sulfuric acid is the largest expenditure of raw materials in the process of making bioethanol from lignocellulosic biomass. Nonetheless, the current technology enables the acid-sugar solution from hydrolysis separated into acid and sugar components by means of chromatographic separation using

commercial available ion exchange resins to separate the components without diluting the sugar. The separated sulfuric acid is recirculated and reconcentrated to the level required by the decrystallization and hydrolysis steps. Using this technology almost up to 100% of the sulfuric acid can be recovered from the process.

7.2.3. State of art scenario

The state of art scenario presented here makes use of the conversion rates from the experiment data (Table 2). Approximately, 200 L of bioethanol yields per dry tones of lignocellulosic biomass and anticipated prices of RM 250 per dry tones of lignocellulosic biomass and RM 264 per tones of 60% concentrated sulfuric acid. The feedstock cost for one litre of bioethanol produced using either from oil palm trunk or wood wastes is estimated at about RM 1.25/litre. The production cost for one litre bioethanol from lignocellulosic biomass is estimated at RM 0.26 with the hydrolysis cost contributed RM 0.20 based on the sulfuric acid is added at a ratio of 5:1 (acid: dry weight of biomass) with acid lost in the sugar stream is not more than 3% during recovery (97% recoverable). Fermentation cost contributed RM 0.06 with the yeast would be grown at the site without cultivation process [38]. Therefore, the total cost per litre of bioethanol produced is RM 1.51 excluding capital and fixed variable costs. However, without the recovery of sulfuric acid during hydrolysis, the cost of bioethanol from lignocellulosic biomass would be rose up to RM7.85, excluding capital and fixed variable costs. With ethanol prices now at RM 2.10 per litre, it is possible for the Malaysia to produce the bioethanol from oil palm trunk and wood wastes, yet it would be not profitable to produce ethanol from lignocellulosic biomass without using the recovery system for sulfuric acid during hydrolysis.

The table below shows different scenario on the biomass feedstock and bioethanol yield that might affect the cost of bioethanol in Malaysia. The scenarios were based on 97% sulfuric acid recovered during hydrolysis and no change on the cost of fermentation production.

Scenario Analysis :

The economic feasibility of bioethanol production in Malaysia from lignocellulosic biomass is highly dependent on the feedstock cost and recovery yield. The cost of feedstock contributed approximately 80% (excluding capital and fixed variable costs) to the total bioethanol cost when the feedstock price estimated at RM 250 per dry weight ton. As the feedstock price increase 5% to 15% per dry ton, the cost of bioethanol increased from as low as 4% up to almost 13%. Higher recovery yield from the bioethanol process will surely reduce the cost of bioethanol produced per litre when the cost of feedstock remains the same. However, as the conversion yield of bioethanol decrease from 200 L per dry weight ton of biomass, the cost of bioethanol per litre increase from 5% up to 17%.

Like corn in the United States and sugarcane in Brazil, the relatively low feedstock cost will only makes this process economically competitive. The cost of producing ethanol from sugarcane in Brazil is estimated at about RM 0.60 per litre, excluding capital costs. U.S. ethanol conversion rates utilizing corn as the feedstock are estimated at approximately 2.65

gallons of ethanol per bushel for a wet mill process and 2.75 gallons per bushel for a dry mill process. Net feedstock costs for a wet mill plant are estimated at about RM 0.30 per litre with total ethanol production costs estimated at RM 0.76 per litre. Net feedstock costs for a dry mill plant are estimated at RM 0.38 per litre with total ethanol production costs at RM 0.76 per litre. Molasses, from either sugarcane or sugar beets, was found to be the most cost competitive feedstock beside the lignocellulosic biomass. Estimated ethanol production costs using molasses were approximately RM 0.92 per litre with a RM 0.66 per litre feedstock cost [39].

	Bioethanol yield (L/T)	Feedstock Price per ton (RM)	Price of Sulfuric Acid per ton (RM)	Cost of Feedstock per litre of bioethanol (RM)	Cost of Production per litre (RM)	Cost of bioethanol per litre (RM)
Laboratory worked	200	250.00	264.00	1.25	0.26	1.51
Scenario 1: Reducing in conversion yield	-5% -10% -15%	Remain Remain Remain	Remain Remain Remain	1.31 1.39 1.47	0.27 0.28 0.29	1.58 (+4.6%) 1.67 (+10.6%) 1.76 (+16.6%)
Scenario 2: Increase of feedstock cost	Remain Remain Remain	+5% +10% +15%	Remain Remain Remain	1.31 1.38 1.44	Remain Remain Remain	1.57 (4.0%) 1.64 (+8.6%) 1.70 (+12.6%)
Scenario 3: Increase of sulfuric acid cost	Remain Remain Remain	Remain Remain Remain	+5% +10% +15%	Remain Remain Remain	0.27 0.28 0.29	1.52 (+0.6%) 1.53 (+1.3%) 1.54 (+2.0%)

Table 3. Cost of bioethanol per litre with different scenario on cost of raw materials and conversion yield

8. Conclusion

The studied lignocellulosic biomass has a higher bioethanol yield per tonne feedstock (L/t) than most of the commercialized bioethanol feedstock. However, improvement had to be made on the conversion efficiency to obtain higher ethanol yield to make it more comparable with the sugar containing and starchy material. The composition of substance that can be converted to glucose played a big influence on the ethanol yield per tonne feedstock. With the large amount of glucose convertible material and abundant availability, these lignocellulosic biomasses are potential feedstock for bioethanol production.

Author details

K.L. Chin¹ and P.S. H'ng

Faculty of Forestry, Universiti Putra Malaysia, UPM Serdang, Selangor, Malaysia

9. References

- [1] Wang M, Saricks C, and Santini D (1999) Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions. Argonne, IL.: USDOE Argonne National laboratory, Center for Transportation Research.
- [2] EPA (2007) Emission Facts; Greenhouse Gas Impacts of Expanded Renewable and Alternative Fuels Use. Emission Facts Report (EPA420-F-07-035). Office of Transportation and Air Quality, EPA. US.
- [3] IEA (2010) Medium Term Oil and Gas Markets 2010, OECD/IEA, Paris.
- [4] F.O. Lights (2011) World Ethanol and Biofuels Report. F.O. Lights. Vol. 10, No. 6.
- [5] Bolling C, Suarez NR (2001) The Brazilian Sugar Industry: Recent Developments. Sugar and Sweetener Situation and Outlook. U.S. Department of Agriculture Economic Research Service, 222-232, September 2001.
- [6] Baucum LE, Rice RW, Schuneman TG (2006) ., Electronic Data Information Source (EDIS) SC032. Agronomy Department, University of Florida, Gainesville, FL.
- [7] Coelho S (2005) Brazilian Sugarcane Ethanol: Lessons Learned. The Brazilian Reference Center on Biomass. STAP Workshop on Liquid Biofuel, New Delhi, India, 29 August-1 September, 2005.
- [8] Berg C (2001) World Fuel Ethanol. Analysis and Outlook. F.O. Lights.
- [9] Pongsawatmanit R, Temsiripong T, Suwonsichon T (2007) Thermal And Rheological Properties Of Tapioca Starch And Xyloglucan Mixtures In The Presence Of Sucrose. Food research international. 40: 239–248 June.

¹ Corresponding Author

- [10] Yoosin S, Sorapipatana C (2007) A Study Of Ethanol Production Cost For Gasoline Substitution In Thailand And Its Competitiveness. *Thammasat int. j. sc. tech.* 12:69-80.
- [11] Cardona CA, Sanchez OJ (2007) Fuel Ethanol Production: Process Design Trends and Integration Opportunities. *Bioresour. technol.* 98: 2415-2457.
- [12] Wang W (2002) Cassava Production For Industrial Utilization In China - Present And Future Perspective. In: *Cassava research and development in Asia: exploring new opportunities for an ancient crop. Seventh regional cassava workshop.* Bangkok, Thailand, October 28–November 1, 2002. pp.33–38.
- [13] Rao DB, Ratnavathi CV, Karthikeyan K, Biswas PK, Rao SS, Vijay Kumar BS, Seetharama N (2004) Sweet Sorghum Cane For Bio-Fuel Production: A SWOT Analysis In Indian Context. *National Research Centre for Sorghum.* pp. 20.
- [14] Agu R, Bringham T, Brosnan J (2006) Production of grain whisky and ethanol from wheat, maize and other cereals. *Journal of the Institute of Brewing.* 112(4): 314-323.
- [15] Baker A., Zahniser S. (2006) Ethanol Reshapes the Corn Market. *Amber Waves. Economic Research Service/USDA.* 4(2): pp 30-35. Available: <http://www.bioenergypro.com/bioenergy-articles/ethanol/ethanol-reshapes-the-corn-market>. Accessed 2012 March 20.
- [16] Moreira JS (2000) Sugarcane for Energy – Recent Results and Progress In Brazil. *Energy for sustainable development.* 6(3): 43–54.
- [17] Ballesteros I, Negro MJ, Oliva JM, Cabañas A, Manzanares P, Ballesteros (2006) Ethanol production from steam-explosion pretreated wheat straw. *Appl Biochem Biotechnol.* 129-132:496-508.
- [18] Demirbas A (2005) Bioethanol From Cellulosic Materials: A Renewable Motor Fuel From Biomass. *Energy sources.* 27: 327–337.
- [19] Bakker RR, Gosselink RJA, Maas RHW, de Vrije T, de Jong E, van Groenestijn JW, Hazewinkel JHO (2004) Biofuel Production From Acid-Impregnated Willow And Switchgrass. In *2nd World Conference on Biomass for Energy, Industry and Climate Protection.* 10–14 May 2004, Rome, Italy. pp. 1467–1470.
- [20] Ballesteros M, Oliva JM, Negro MJ, Manzanares PI (2004) Ethanol From Lignocellulosic Materials By A Simultaneous Saccharification And Fermentation Process (SFS) With *Kluyveromyces marxianus* CECT 10875. *Process Biochemistry.* 39(12):1843-1848.
- [21] F.O. Lights (2008) World Ethanol and Biofuel Report. *F.O. Lights.* Vol.4, No.7. pp.71-92.
- [22] Sánchez OJ, Cardona CA (2008) Trends In Biotechnological Production Of Fuel Ethanol From Different Feedstocks. *Bioresour. technol.* 99: 5270-5295.
- [23] Beville K (2001) Ethanol Producer Magazine, BBI International.
- [24] Mosier N, Wyman CE, Dale BD, Elander RT, Lee YY, Holtzapple M, Ladisch CM (2005) Features Of Promising Technologies For Pretreatment Of Lignocellulosic Biomass. *Bioresour. technol.* 96: 673–686.

- [25] Puls J, Schuseil J (1993) Chemistry Of Hemicelluloses: Relationship Between Hemicellulose Structure And Enzymes Required For Hydrolysis. In: M.P. Coughlan, G.P. Hazlewood, editors. Hemicellulose and Hemicellulases, Portland Press Research Monograph. pp. 1–27.
- [26] Iranmahboob J, Nadim F, Moemi S (2002) Optimizing Acid-Hydrolysis: A Critical Step For Production Of Ethanol From Mixed Wood Chips. *Biomass and bioenergy*. 22: 401–404.
- [27] Grahmann K, Torget R, Himmel M (1985) Optimization Of Dilute Acid Pretreatment Of Biomass. *Biotechnology and bioengineering symposium*. 15: 59–80.
- [28] Farooqi R, Sam AG (2004) Ethanol as A Transportation Fuel. Centre for Applied Business Research in Energy and the Environment (CARBREE) Climate Change Initiative. University of Alberta, Canada.
- [29] Van Groenestijn J, Hazewinkel O, Bakker R (2006) Pretreatment Of Lignocellulose With Biological Acid Recycling (Biosulfurol Process). *Zuckerindustrie*. 131(9): 639–641.
- [30] Chandel AK, Chan ES, Rudravaram R, Narasu ML, Rao LV, Ravindra P (2007) Economics and Environmental Impact of Bioethanol Production Technologies: An Appraisal. *Biotechnology and molecular biology review*. 2(1): 14–32.
- [31] Schell DJ, Farmer J, Newman M and McMillan JD (2003) Dilute-Sulfuric Acid Pretreatment of Corn Stover in Pilot-Scale Reactor: Investigation of Yields, Kinetics, and Enzymatic Digestibilities of Solids. *Applied biochemistry and biotechnology*. 105–108: 69–86.
- [32] Thomsen MH, Thygesen A, Jorgensen H, Larsen J, Christensen BH, Thomsen AB (2006) Preliminary Results On Optimizing Of Pilot Scale Pretreatment Of Wheat Straw Used In Coproduction Of Bioethanol And Electricity. *Applied Biochemistry and Biotechnology*. 129–132: 448–460.
- [33] Bon EPS, Ferrara MA (2007) The Role of Agricultural Biotechnologies for Production of Bioenergy in Developing Countries. FAO seminar, Rome, 12 October 2007.
- [34] AIM, 2011. National Biomass Strategy 2020: New wealth creation for Malaysia's palm oil industry. Agensi Inovasi Malaysia. Putrajaya.
- [35] Chin KL, H'ng PS, Wong LJ, Tey BT, Paridah MT (2010) Optimization Study Of Ethanollic Fermentation From Oil Palm Trunk, Rubberwood and Mixed Hardwood Hydrolysates Using *Saccharomyces cerevisiae*. *Bioresour. technol*. 101: 3287–3291.
- [36] Chin KL, H'ng PS, Wong LJ, Tey BT, Paridah MT (2011) Production Of Glucose From Oil Palm Trunk and Sawdust Of Rubberwood and Mixed Hardwood. *Applied energy*. 88: 4222–4228.
- [37] Wang L, Sharifzadeh M, Templer R, Murphy RJ (2012) Technology Performance And Economic Feasibility Of Bioethanol Production From Various Waste Papers. *Energy environ. sci*. 5: 5717–5730.
- [38] Farone WA, Cuzens JE (1996) Method of Separating Acids and sugars Resulting from Strong Acid Hydrolysis. U.S. Patent No. 5,580,389. December 3.

- [39] Shapouri H, Salassi M, Fairbanks JN (2006) The Economic Feasibility Of Ethanol Production From Sugar In The United States. USDA's Renewable Energy. United State Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses.

IntechOpen

IntechOpen