BIOETHANOL – FUEL OR FANCY?

Ethical Solutions, February 2007

Ethical Solutions **was commissioned by Glasu LEADER+ to look at the feasibility of producing bioethanol from low-grade feedstock, such as hedge clipping, fallen leaves, etc. We have interpreted this in two ways: firstly, the technical feasibility in terms of existing technology and ongoing developments in the sector; and, secondly, whether it is likely to be an appropriate technology for local companies, small scale developers or the local authority.**

In essence, we have concluded that, whilst it is technically possible, the small-scale of bioethanol fuel from these feedstocks is not viable at the present time for these user groups. The production of bioethanol from higher-grade feedstocks (i.e. high starch feedstocks) could possibly be considered however, if readily available biomass materials were locally available.

At the current time, the technology required for producing bioethanol from woody feedstock is still in its infancy, both technically and economically. Much work is being undertaken globally in both the public and private sectors to advance this technology, but it has not reached the stage where small-scale production is viable. This is likely to change in the future as new enzymes are being engineered to deal with this challenging, but hugely promising, raw material.

The following document provides an outline of our researches, some of the political framework surrounding biofuels, and an overview of the production methods for the main types of bioethanol. Further information from a variety of sources has been provided for reference purposes and as supporting evidence.

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Ethical Solutions is a research & product design company with a special interest in sustainable energies, the environment, and sustainable rural development. Ethical Solutions seeks to find practical and accessible solutions that fit real needs.

For more information, please visit our website: www.ethical-solutions.co.uk

1 Biodiesel and Bioethanol

In essence, biodiesel is a substitute for diesel, bioethanol an alternative to petrol. At the current time, biodiesel has a greater degree of acceptance in the UK. This seems to be largely because most modern diesel engines will accept biodiesel/diesel mixtures without modification. Older diesel engines tend to be able to run on pure bioethanol without any modification.

Biodiesel is usually made from vegetable oils, such as rapeseed oil, but it is also possible to produce it from animal fats. Depending on the engine type, it can be used in any mixture with conventional diesel from 5% up to 100% pure. Much of what is sold as biodiesel in the UK is what is sometimes called 80/20. This contains 20% biodiesel.

Biodiesel can, depending on the quality of its manufacture, have a slightly higher level of moisture and more of some other minor impurities than conventional diesel. These, it is claimed by some vehicle manufacturers (particularly in the UK), can cause internal corrosion in the engine. Curiously, many of the same manufacturers allow their vehicles to be run on the Continent on pure biodiesel without voiding the warranty.

Bioethanol is ethanol (C_2H_5OH), an alcohol produced by the biological fermentation of carbohydrates derived from plant material. Synthetic ethanol is classed as a fossil fuel. Bioethanol is a clear colourless liquid with a mild odour (apparently similar to whisky) that will biodegrade readily in air, water and soil. Feedstocks for its production vary from sugar beet to oats, depending largely on local availability. There is much work being undertaken at present, particularly in Canada, South America and the USA, to make the production of ethanol from wood-based materials more cost- effective.

"*It is generally accepted that on a well to wheel basis, bioethanol gives a 70% carbon dioxide reduction versus petrol. This means that a 5% blend produces 3.5% less carbon emissions, whilst an 85% blend (like E85) would achieve a 50% reduction.*" Energy Saving Trust

2 *Bioethanol Types*

There are two main types of bioethanol:

1. ***Starch** (or **Sugar)***– produced from carbohydrate-rich materials, such as corn, potatoes, sugar beet or oats
2. ***Lignocellulosic** (or **Cellulosic)*** – produced from woody materials such as corn stover (the waste dried stalks and leaves) and wood processing waste. This type of bioethanol is occasionally referred to as 'second generation' or 'advanced biofuels'

A variety of feedstocks are potentially suitable for bioethanol production, including:

- Alfalfa
- Bagasse (sugar production by-product)
- Barley
- Corn (stover & cobs)
- Cotton
- Fruit (e.g. orange or apple pulp waste)
- Grass clippings
- Jerusalem artichoke
- Hemp
- Leaves
- Molasses
- Paper
- Potatoes
- Skimmed milk
- Sorghum
- Spent hops
- Straw
- Sugar beet
- Sugar cane
- Sunflower
- Sweet potatoes
- Wheat
- Whey
- Wood (e.g. process waste or willow)

This list is far from exhaustive, and the output in terms of usable alcohol varies considerably (dependant largely on starch content and how accessible the starch is for fermentation). There has even been some research in the USA on using municipal solid waste (household waste and paper products) as a feedstock (US Department of Energy).

A new and promising technology has the potential to make ethanol fuels much more practical. This method for producing ethanol not from corn kernels, but from the plant's stalk, roots and leaves, is known as cellulosic material. So-called cellulosic ethanol has been around for years, but breaking down the cellulose to make it fermentable was inefficient, expensive, and manufactured a fair amount of pollution. But only until recently have companies developed a process for making it more efficiently. Cellulosic ethanol made from stalks and husks (and other plant cellulose material) still has to be fermented, but it uses cast-off waste products of food that's already being grown.

http://www.piribo.com/publications/biotechnology/us_bioethanol_cellulosic_ethanol_market.html

Much of the current commercial production of bioethanol is from sugarcane, maize and sugar beet, as these all represent fairly high yield, readily accessible sugar sources. The technology to produce ethanol from lignocellulosic feedstock is still struggling to become economically competitive. Lignocellulosic biomass is a readily available and often waste material, particularly from the food processing and forest products industries. This makes it an ideal candidate for those seeking locally-sourced, low cost feedstocks.

3 An Introduction to Bioethanol Fuel

Ethanol is one of a group of four organic alcohols (the other three being methanol, butanol and propanol (isopropyl alcohol)) that are all of interest as fuels for use in current engines. Because of the amount of oxygen in the ethanol molecules, ethanol burns more completely.

The by-products of ethanol combustion are:

- Carbon dioxide
- Water
- Heat

Burning ethanol does not produce carbon monoxide, unlike burning fossil fuels such as petrol or diesel, but the carbon dioxide emissions are higher. This is not regarded to be a serious matter as the carbon has been drawn from the air by the feedstock, so there is no net modern release. NO_x (nitrogen oxides produced during combustion) emissions are also lower. On the negative side, ethanol can be corrosive to some plastics and rubber used in modern fuel systems, and has approximately 37% less energy per litre than petrol.

> **Because E85 fuel only has around 80% of the energy of gasoline, full usage of the said fuel alternative remains to be in question. Certainly, the lack of energy content in E85, which accounts for the 2% to 30% loss in gas [petrol] mileage, is not to be discounted especially by the public. Also, it has been observed with fuel combination, gas mileage drops as there is less gasoline present in the fuel mixture.**
>
> *www.cleanairtrust.org*

Bioethanol can be used as a petrol additive, or as a substitute. It is more commonly used as an additive as up to 5% can be used in petrol engines without any modification (in accordance with the EU quality standard EN 228). Higher levels of bioethanol require engine modifications. These consist largely of replacing rubber seals (usually with nylon) and any uncoated magnesium and aluminium parts.

> ***To convert a conventional spark-ignition engine vehicle to run on pure bioethanol requires the adjustment of the ignition timing, and the fitting of a larger fuel tank due to the fuel's low energy density. As alcohol fuels degrade certain types of rubber and accelerate the corrosion of several metals, some engine components may also need to be replaced. Pure bioethanol is difficult to vaporise at low temperatures – E95-E100 vehicles can be therefore difficult to start in cold weather. For this reason, the fuel is usually blended with a small amount of petrol to improve ignition (E85 is a common high percentage blend).***
>
> www.whatgreencar.com/bioe.php

Most modern vehicle warranties are rendered invalid by the use of more than 5% bioethanol in the fuel. Part of the problem is that the vehicle computer system, the ECU, is set up to read the only the limited amounts of oxygen in conventional fuel. Ethanol has a significantly higher level of oxygen, and so can destroy an engine's oxygen sensors and ECU. A standard petrol engine uses a ratio of air mass to fuel mass of 14.6:1; for pure ethanol the ratio is 9:1.

Starch ethanol is already in use in petrol in the UK, usually replacing lead as an oxygenator and octane-enhancer. This was a common practice amongst fuel manufacturers until the 1950's, when lead displaced ethanol as a fuel-enhancer as it was a much cheaper additive and slowed down the combustion of the petrol.

"People often say that the biggest problem with high ethanol contents is that it is very corrosive, but this isn't true. The biggest issue is that ethanol is hygroscopic. It absorbs water easily, which causes the fuel to dissolve corrosive salts from any available source it comes into contact with. It's not the ethanol that is corrosive, it's what it brings with it."

Julie Galante-Fox, biofuels specialist, Delphi www.delphi.com

Bioethanol can also be converted to etherised bioethanol (ethyl tertiary butyl ether: ETBE), which can be used as a 15% blend with petrol. This is common practice in France and Spain. EN standard E85 (85% bioethanol and 15% petrol) can be used in flexible fuel vehicles (FFVs) produced by the likes of Ford and Saab. E95 (for high compression engines) is 95% bioethanol. It is sometimes referred to as 'bus fuel' as it is usually used for diesel-powered engines. E85 and E95, because of their differing spark ratios, are not interchangeable. E10 (10% bioethanol, 90% petrol) is also known as gasohol.

The jury is still out and arguing as to whether the production processes involved in bioethanol are any better for the environment than the production of petrol. According to the US Energy Information Administration (http://eia.doe.gov/), "*converting cellulose to ethanol increases the net energy balance of ethanol compared to converting corn to ethanol*". On the other hand, E85 reportedly has a lower energy value than petrol and so more E85 is required to cover the same distance as a standard petrol engine.

What cannot be argued, however, is the fact that burning fossil fuels is not a long term option, whether it be for reasons of sustainability (fossil fuel supply levels) or environmental issues (putting fossil carbon into the atmosphere).

Bioethanol can be blended into petrol, where it offers air quality as well as carbon benefits. Bioethanol can be produced from a number of crops including sugar beet. Future technologies may allow bioethanol to be produced from a variety of source materials including wood, grass, straw and green waste.

www.dft.gov.uk

The US has developed a well-established bioethanol network, and has roughly 6 million E85 vehicles in current use. The Brazilian government is probably the most pro-active supporter of bioethanol anywhere in world, and has passed legislation requiring cars to be suitable to run on a 25% ethanol blend. Approximately 60% of new cars sold in Brazil run on 100% ethanol fuelled. Brazil produces about 4 billion gallons annually from sugar cane. Other countries actively pursuing alcohol fuel production include Argentina, Kenya, Malawi, South Africa and Zimbabwe (all sugar producing nations), and also Bolivia, Paraguay, Honduras and Costa Rica. The UK government has set a target of 5% market share for biofuels by 2010.

"In Sweden, where 80 per cent of Focus models sold are FFVs, bioethanol costs more than 40 per cent less than petrol. The Somerset project draws on the Swedes' experience of establishing regional bioethanol distribution networks and the introduction of flexi fuel cars.

In Somerset, Wessex Grain is planning a new bioethanol production plant next to an existing grain storage site in Henstridge. The facility will be able to convert 340,000 tonnes of wheat into 131,000,000 litres of ethanol a year at full capacity from 2007."

www.ford.co.uk

4 Government support

Bioethanol is inevitably going to become much bigger business in the UK over the next ten years and, subject to ongoing technological developments, rapidly catch up biodiesel in terms of public acceptance. A number of companies, both indigenous and overseas, are working to set up new production facilities in the UK. One example of this is Losonoco, a US company that is reportedly planning to build a £60m bioethanol plant in Billingham (Teeside) by the end of 2008.

Hopefully increasing public awareness of the benefits of biofuels and their increasing availability will help to spur the government into seeing the potential environmental benefits of biofuels as being a bigger carrot than the revenue generated by tax levies. The technical and market advancement of biofuels could be considerably accelerated if genuine government in the form of legislation and tax breaks were made available as incentives.

European Directive 2003/30/EC promotes the replacement of fossil fuels by biofuels, including bioethanol. Although the UK government has adopted a policy of encouraging biofuels, the taxation of alternative fuels generally is almost as onerous as those for conventional (fossil) fuels, and the UK is far behind of other European countries such as Sweden in terms of government support for the biofuel industry. The UK government currently allows a fuel duty rebate of 20p per litre on bioethanol and a £10 reduction in Vehicle Excise Duty (VED) for environmentally friendly cars like flexible fuel vehicles.

According to BEST[1], typical obstacles to the development of high blends such as E85 amongst European member states are:

- Lack of standards and harmonisation of fuels and fuel handling
- Obsolete quality, safety and tax legislation (particularly national taxes being based per litre, giving benefit to energy-rich fossil fuels)

BEST has commented that a growing awareness of climate change is a major factor favouring the use of biofuels[2]. On the converse, they see the main obstacles as being:

- Slow introduction of regulations for handling, storing and dispensing biofuels
- Focus on low rather than high blends such as E85, slowing the shift of vehicle technology
- Current cost of biofuels

> **"Our analysis determined that both corn and cellulosic ethanol production return renewable energy on their fossil energy investments, though the results indicate that cellulosic ethanol production will be preferable to corn ethanol production. On the surface, cellulosic ethanol simply delivers profoundly more renewable energy than corn ethanol. And considered more closely across the social, economic, and environmental factors beyond simple energy return on investment, cellulosic ethanol production promises to consume less petroleum, produce fewer greenhouse gases, and require less land compared to corn ethanol. However, the corn ethanol industry is the foundation from which a much larger biofuels economy will grow. As the energy return on investment shows, corn ethanol is providing important fossil fuel savings and greenhouse gas emissions reductions today, and it is providing an even bigger oil savings."**
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> *'Ethanol: Energy Well Spent'*
> *(Natural Resources Defence Council and Climate Solutions, Feb 2006)*

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[1] *BEST – Bioethanol for Sustainable Transport, an EU project within the FP6 programme*
[2] *BEST, Consultation on Review of Biofuels Directive*
http://ec.europa.eu/energy/res/legislation/doc/biofuels/contributions/industry/best.pdf

5 Feeding the Multitudes or Fuelling Vehicles – a Worthwhile Investment?

One potentially significant factor standing in the way of far greater use of bioethanol as a fuel is that it is conventionally produced from products that are also food sources for humans and livestock. This is where the argument arises that we are going to run out of growing space if the land is being asked to produce both food and fuel. On the other hand, some fast growing species like switchgrass can be grown on land not suitable for other food or cash crops and yield high levels of bioethanol per acre.

Population growth and food availability must inevitably play a part in the commercialisation of bioethanol from food-related crops. Some have argued that as lignocellulosic ethanol can be made from waste biomass, the impact on food crops is negligible. That is only true so long as essential food crops are not displaced, as they have been in the increasing land being put to palm oil production in some poorer regions.

Cellulose is the primary structural material of green plants. Lignin and cellulose, considered together, are termed lignocellulose, which is argued to be the most common biopolymers on Earth. Cellulose is not digestible by humans, making it an ideal candidate for fuel production.

> **Those who have been promoting these fuels are well-intentioned, but wrong. They are wrong because the world is finite. If biofuels take off, they will cause a global humanitarian disaster.**
>
> **Road transport in the United Kingdom consumes 37.6 million tonnes of petroleum products a year. The most productive oil crop which can be grown in this country is rape. The average yield is between 3 and 3.5 tonnes per hectare. One tonne of rapeseed produces 415 kilos of biodiesel. So every hectare of arable land could provide 1.45 tonnes of transport fuel.**
>
> **To run our cars and buses and lorries on biodiesel, in other words, would require 25.9m hectares. There are 5.7m [hectares] in the United Kingdom. Switching to green fuels requires four and half times our arable area. Even the EU's more modest target of 20% by 2020 would consume almost all our cropland.**
>
> **If the same thing is to happen all over Europe, the impact on global food supply will be catastrophic: big enough to tip the global balance from net surplus to net deficit. If, as some environmentalists demand, it is to happen worldwide, then most of the arable surface of the planet will be deployed to produce food for cars, not people.**
>
> **This prospect sounds, at first, ridiculous. Surely if there was unmet demand for food, the market would ensure that crops were used to feed people rather than vehicles? There is no basis for this assumption. The market responds to money, not need. People who own cars have more money than people at risk of starvation. In a contest between their demand for fuel and poor people's demand for food, the car-owners win every time.**
>
> *Monbiot, 2004*
> http://www.monbiot.com/archives/2004/11/23/feeding-cars-not-people/

Cellulosic ethanol production is still being developed as a commercial technology and, at the current time, involves a much more expensive process than starch ethanol. That said, however, there is a strong argument in favour of using lignocellulosic feedstocks in that land used for their growth can effectively be made to serve two functions. This is particularly the case in the use materials such as corn stover, where the corn is used for humans and animals, and the 'waste' stems and leaves for the manufacture of ethanol.

If bioethanol is to become a viable fuel for the future, lignocellulosic production technologies will have to become economically viable and, as a result, more widespread.

"*We have the technical ability, but making ethanol production economical is the problem.*" *Ethanol now comes from corn kernels. "But that is food. If we want to produce 30 to 60 billion gallons of ethanol, which is what is needed to meet the President's goal, we have to use the entire plant, or the stover (leaves, stalks, and cobs), and leave the kernels as food*."

Y.H. Percival Zhang; College of Agriculture and Life Sciences, Virginia Tech

As to whether the UK can produce sufficient ethanol feedstock, we currently have a wheat surplus of over 3 million tonnes. As this is surplus to the UK's food needs, it could be used for bioethanol production. This amount of wheat could produce about 1 million tonnes or fuel, or approximately 5% of the UK petrol market. If set-aside land was added into this equation, a further 1.5% of the country's energy needs could be met. This, of course, does not take into consideration the waste materials that could also be used for bioethanol production, such as food processing, paper, and forest industries waste products.

"Cellulosic crops, like fast growing tree plantations, use relatively little fertilizer and use less energy in harvesting than annual row crops. The crop itself is burned to provide energy for the manufacture of ethanol and other co-products. A major co-product of cellulosic crops is lignin, which currently is used only for fuel but which potentially has a high chemical value. Were it to be processed for chemical markets, the net energy gain would be even greater." (Lorenz & Morris, ILSR)

According to a study undertaken by the Argonne National Laboratory (University of Chicago) on behalf of the US Department of Energy, cellulosic ethanol reduces greenhouse gas emissions by 85% compare to reformulated petrol. Starch ethanol reduces greenhouse gases by up to 29%, as it often uses natural gas for the process energy requirements.

Energy Used to Make Ethanol From Corn and Cellulose (Btus per Gallon of Ethanol)

	Corn Ethanol (Industry Average)	***Corn Ethanol*** (Industry Best)	***Corn Ethanol*** (State-of-the-Art)	***Cellulosic Crop-Based Ethanol***
Fertilizer	12,981	7,542	3,869	3,549
Pesticide	1,060	643	406	437
Fuel	2,651	1,565	1,321	8,120
Irrigation	7,046	6,624	6,046	--
Other (Feedstock)	3,395	3,248	3,122	2,558
Total (feedstock)	*27,134*	*19,622*	*14,765*	*14,663*
Process Steam	36,732	28,201	26,185	49,075
Electricity	14,444	7,300	5,148	8,925
Bulk Transport	1,330	1,100	800	1,330
Other (process)	1,450	1,282	1,050	2,100
Total (processing)	*53,956*	*37,883*	*33,183*	*61,430*
TOTAL ENERGY INPUT	**81,090**	**57,504**	**47,948**	**76,093**
Energy in Ethanol	84,100	84,100	84,100	84,100
Co-product Credits	27,579	36,261	36,261	115,400
TOTAL ENERGY OUTPUT	**111,679**	**120,361**	**120,361**	**199,500**
Net Energy Gain	30,589	62,857	72,413	123,407
Percent Gain	**38%**	**109%**	**151%**	**162%**

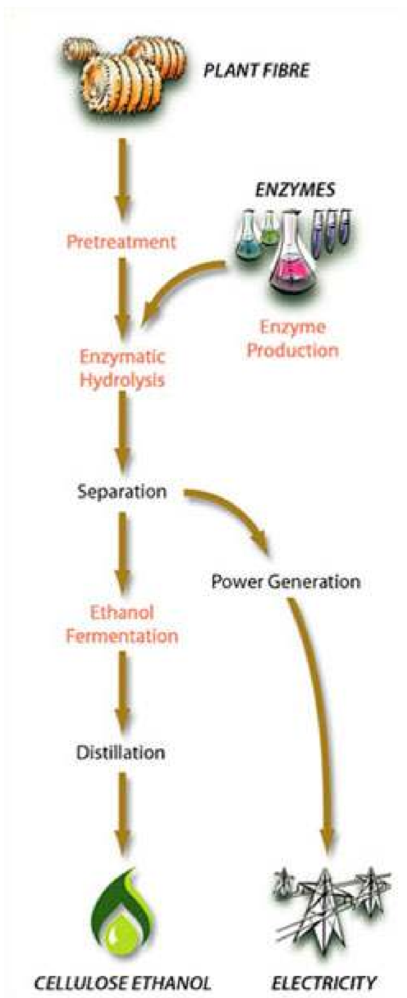
Source: How Much Energy Does It Take to Make a Gallon of Ethanol? David Lorenz and David Morris ©1995 Institute for Local-Self Reliance (ILSR)

Motivation for Small Bioethanol Plants

- **It is now possible to supply modern bioenergy complexes for remote rural villages based on different crops able beyond the satisfaction on the essential needs of the population (food, animal feed, energy), to produce an extra income from the surpluses sale for an economic sustainable activity.**
- **The comprehensive utilisation and processing of the biomass resource in integrated complexes with the simultaneous production of several high value commodities is essential for the improvement of the economic activity and for a large scale sustainable deployment of these bioenergy complexes.**
- **These Integrated Complexes could provide a vital contribution for a general rural socio-economic development and for considerably increasing the Index of Human development of the population (60-70%).**

'Microdistillery for Decentralised Bioethanol Production',
(LAMNET, Technological Instrument for Rural Development)

Iogen[3], a Canadian biotechnology company, became the first to commercially retail cellulosic ethanol in 2004, mainly to the Canadian government. A number of other companies are working on developing commercially viable lignocellulosic ethanol production technologies.



Iogen: Cellulosic Ethanol Process (Canada)

[3] *Iogen also develops, manufactures and markets enzymes used to modify and improve the processing of natural fibres within the textile, animal feed, and pulp and paper industries*

December 21, 2006

For Immediate Release

GREENFIELD ETHANOL

Greenfield Ethanol and Sunopta Create Cellulose Ethanol Joint Venture

TORONTO – GreenField Ethanol Inc., Canada's leading ethanol producer, and SunOpta Inc today announced a new joint venture to develop a commercial-scale plant that will produce ethanol from wood chips.

The plant is slated to produce 40 million litres of cellulosic ethanol per year, making it the first operating commercial cellulose ethanol plant in the world using wood chips.

"This partnership combines decades of GreenField's experience in developing world-class ethanol plants and SunOpta's experience in developing cellulose pre-treatment technologies," said Bob Gallant, President and CEO of GreenField Ethanol. "This new joint venture creates unparalleled experience in developing cellulose technology."

GreenField Ethanol and SunOpta are actively involved in selecting a site for the plant in Ontario or Quebec.

www.greenfieldethanol.com

Genencor and Novozymes have both received funding from the US government Department of Energy to research reducing the cost of cellulase, a key enzyme in the production of cellulosic ethanol by enzymatic hydrolysis.

6 Bioethanol Production

6.1 Overview

Bioethanol is most commonly produced by the fermentation of sugar and starch from organic materials (biomass). Sugar-rich biomass can be directly fermented, whereas starch-containing and cellulosic materials have to first have their sugars released (hydrolysed). The cellulose and hemicellulose portions are hydrolysed, usually by enzymes or dilute acids, into sugar that is then fermented. Anaerobic digestion of the material during fermentation converts the sugars into alcohol and carbon dioxide through the action of bacteria such as yeast. The resultant liquid is then distilled to produce pure ethanol. At its most efficient, approximately 1kg of bioethanol will be produced from 3kg of biomass.

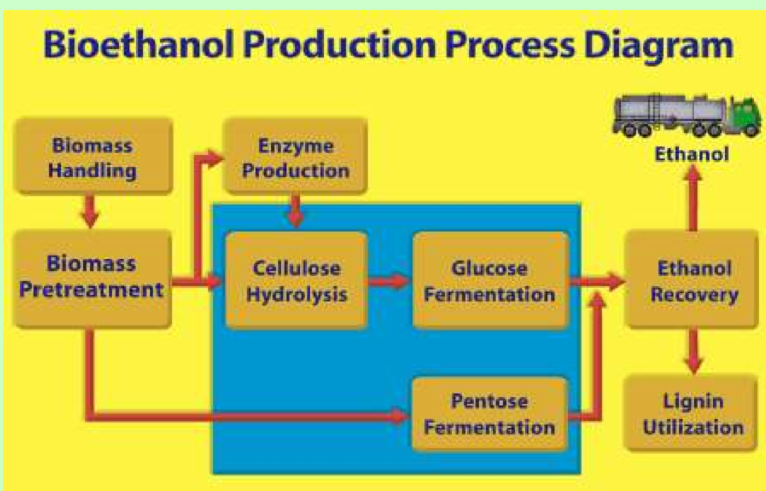
Biomass wastes contain a complex mixture of carbohydrate polymers that make up the cell walls of the organic materials. These are:

- Cellulose
- Hemicellulose
- Lignin

Cellulose accounts for between 40-60% (by weight) of the biomass, depending on the feedstock. It is a polysaccharide (complex sugar polymer) made from glucose, a six-carbon sugar. The crystalline structure of cellulose makes it resistant to hydrolysis.

Hemicellulose is a complex polysaccharide made from a variety of five- and six-carbon sugars, found in levels of between 20-40% of biomass by weight. Its random structure is readily hydrolysed by dilute acid or enzymes, but the sugars are difficult to ferment.

Lignin is an integral part of the cell walls of plants. A complex polymer, it makes up between 10-24% by weight of the biomass, and remains as residual material after the sugars have been converted into ethanol. The lignin remaining is usually used as a fuel to produce steam and/or electricity for the ethanol production plants boilers



Source: US Department of Energy, Energy Efficiency & Renewable Energy
http://www1.eere.energy.gov/biomass/abcs_biofuels.html#feed

6.2 Processes

There are two main processes for the production of lignocellulosic ethanol:

- Hydrolysis followed by fermentation, and
- Synthesis gas fermentation.

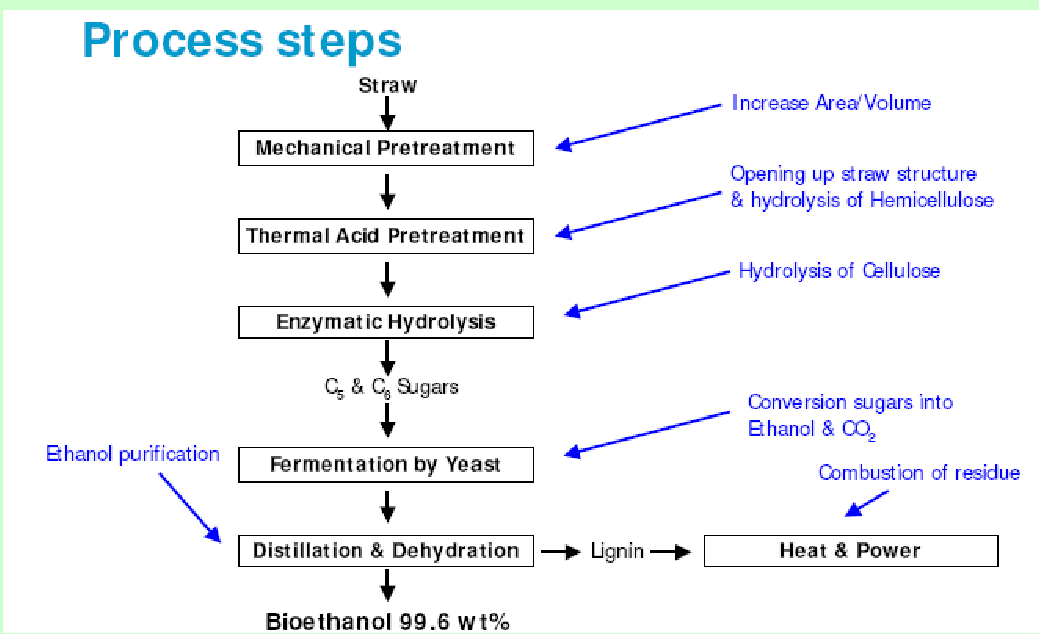
In the latter method, the biomass feedstock is first subjected to a high temperature gasification process in order to convert it into a synthesis gas (CO, CO_2, and H_2). Anaerobic bacteria such as *Clostridium ljungdahlii* are then used to convert the gas into ethanol. This process is still somewhat underdeveloped as a commercial technology and so will not be explored in this document.

The production process for starch ethanol is rather simpler and more accessible for micro-production than that for lignocellulosic ethanol, involving a process very much akin to drinking alcohol manufacture. Although a description of the production process is not directly relevant here, information on the processes involved and some links to additional sources of assistance has been included in the supporting evidence section.

6.2.1 Hydrolysis

Hydrolysis is a chemical reaction that converts complex polysaccharides in the feedstock into simple sugars, either chemically (using acids) or biologically (using enzymes). The three principle forms of hydrolysis are:

- ***Concentrated acid***
  Concentrated acid (hydrochloric, sulphuric or hydrofluoric) is added to dry biomass at ambient temperature. Water is then added to dilute the acid to between 20-30% and the mixture is heated. The resultant gel is pressed to release the acid sugar mixture for separation. Sulphuric acid is used at concentrations of up to 77%.
- ***Dilute acid***
  This process uses low concentration sulphuric acid and temperatures of up to 200ºC to process the cellulosic biomass. It is regarded by many to be the simplest and most efficient form of hydrolysis. The concentration of sulphuric acid used ranges from 0.5-2%
- ***Enzymatic***
  This form of hydrolysis is still in its virtual infancy and, as such, is very expensive. One method being developed is SSCF (simultaneous saccharification and co-fermentation), combing hydrolysis and fermentation in one vessel



Process Design for an Integrated Lignocellulose to Bioethanol Production Plant
Energy Research Centre of the Netherlands, Delft University of Technology
http://www.bioenergynoe.org/docs/Presentation%20NoE%20Meeting%20Helsinki%20-%20Jarno%20Kuijvenhoven.PDF

6.2.2 Fermentation

Fermentation involves a series of chemical reactions caused by yeast or bacteria feeding on the sugar solution formed by hydrolysis. The by-products are ethanol and carbon dioxide within the fermented mash. This mash contains up to 30% solids, with an alcohol content of up to 15%. Fermentation can take around three days to complete.

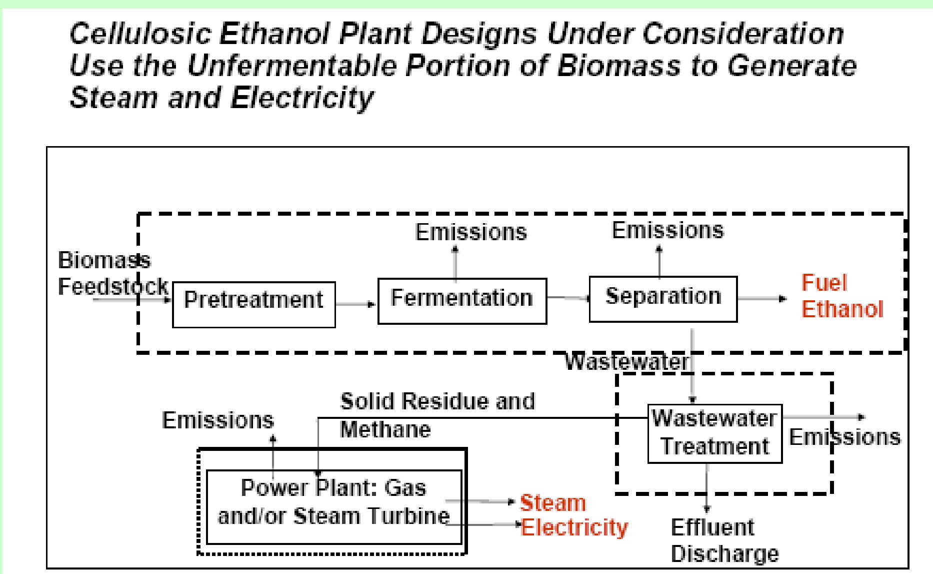
6.2.3 Distillation

Fractional distillation is employed to separate the ethanol from the excess water. This involves boiling the mixture. As the boiling point of ethanol is 78.3ºC, whereas water boils at 100ºC, the ethanol evaporates before the water can. This vapour is collected and condensed back into a liquid form that is usually 95% ethanol (with 5% water). This can be further dried to remove almost all of the remaining water. The outcome is 99.7% pure ethanol.

It is then necessary to denature the ethanol, i.e. to make it poisonous.

> "*Ethanol is only considered bioethanol after it has been denatured and is therefore no longer an alcohol. Customs have approved a formulation of denatured alcohol for use in the manufacture of bioethanol or bioethanol blend. The formulation is based on the addition of methanol and denatonium benzoate to the ethanol.*"
>
> HM Customs & Revenue[4]

Depending on the original feedstock, the 'whole stillage' that is the by-product of distillation can be separated to produce 'distillers grain' and 'evaporation solids' that can be used as protein-rich, economical animal feeds, or can be processed to create biogas.



Source: 'The Debate on Energy & Greenhouse Gas Emissions Impacts of Fuel Ethanol', Wang, Argonne
www.transportation.anl.gov/pdfs/TA/347.pdf

[4] *For more information, see:*
http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageExcise_ShowContent&id=HMCE_PROD1_024145&propertyType=document

6.3 Handling & Storage

There are some distributional issues for bioethanol and bioethanol-petrol blends because bioethanol, unlike petrol, mixes fairly readily with water. Any increase in the water content in the blend will normally cause it to fail regulatory standard specifications.

Bioethanol's affinity to water has lead a number of countries to adopt the practice of blending bioethanol with petrol as close to the end of the supply chain as possible. One method commonly used is to perform the mixing as the tankers are being filled at the terminals.

There are also some issues to do with the volatility of low-blends, due to their high petrol content. For specific guidance, contact the Health & Safety Executive.

A copy of the 'Guidebook for Handling, Storing, & Dispensing Fuel Ethanol' (prepared for the U.S. Department of Energy by the Argonne National Laboratory) is included with the supporting evidence for this document. Whilst the legislative section is clearly presented for the US market, the technical and safety issues will be basically the same as for Europe.

7 Links and sources of Additional Information

ESRU (Energy Systems Research Unit), Strathclyde University
Info about bioethanol, benefits & methods of production
www.esru.strath.ac.uk/EandE/Web_sites/02-03/biofuels/what_bioethanol.htm

Energy Saving Trust (EST)
General info about bioethanol, including where to buy it
www.est.org.uk/fleet/Vehicles/Alternativefuels/Bioethanol/

British Bioethanol (British Sugar)
Various info about biofuels
www.britishbioethanol.co.uk

Arkenol
Info on producing ethanol using concentrated acid hydrolysis
www.arkenol.com/Arkenol%20Inc/index.html

INRA (L'institut National de la Recherche Agronomique)
INRA is researching enzymes for hydrolysing lignocellulosic biomass
www.international.inra.fr/research/some_examples/filamentous_fungi_to_produce_biofuels

Vermont Biofuels Association
Info on processes and links to projects. Also info on biodiesel
www.vermontbiofuels.org

Somerset Biofuel Project
Introducing bioethanol to the UK transport fuel market
www.biomatnet.org/publications/1993som.pdf

Biogasol
Danish company, based at the Technical University of Denmark; working to make lignocellulosic bioethanol production cost-effective
http://www.biogasol.dk/3me.htm

Iogen
Canadian company producing and developing lignocellulosic bioethanol
www.iogen.ca

British Association for Biofuels & Oils
Info on fuel duties, rebates, etc. Also fuel characteristics and production costs
http://www.biodiesel.co.uk/scott_wilson_report.htm

Z Facts
All sorts of information and news about bioethanol
http://zfacts.com/p/85.html

Journey to Forever
Wood Ethanol Report – Technology Overview
http://journeytoforever.org/biofuel_library/WoodEthanolReport.html

Tall Corn Ethanol
Produce 40 million gallons of corn ethanol annually
www.tallcornethanol.com

E85 Whipnet
All kinds of info about E85 fuel and bioethanol generally
http://e85.whipnet.net/

Range Fuels
"Saving our planet one gallon at a time"… Produce cellulosic ethanol
www.rangefuels.com

Energy Saving Now
Use of ethanol fuel for cars

http://energysavingnow.com/biomass/carsbiofuel.shtml

Ethanol Expansion Program (EEP), Canada

Government programme to roll out ethanol production & use in Canada
http://oee.nrcan.gc.ca/transportation/fuels/ethanol/eep.cfm?attr=8

Running on Alcohol

Everything to do with making 'backyard' fuel alcohol including instructions
http://running_on_alcohol.tripod.com/index.html

Revenoor

US company producing backyard fuel alcohol stills
www.revenoor.com/GenWebPage.ihtml?formID=1

Green Fuels Ltd

UK company working on designs for biodiesel & bioethanol plants
http://www.greenfuels.co.uk/about_bioethanol.htm

The New Rules Project

The Energetics of Ethanol – Introduction and Links to Studies
http://www.newrules.org/agri/netenergy.html