

Ethanol

Lab scale

Bench scale

Pilot Plant

Demonstration

Production

Introduction

Ethanol, also known as ethyl alcohol, pure alcohol, grain alcohol, or drinking alcohol, is often abbreviated as EtOH. EtOH is a light alcohol and is a volatile, colourless, flammable liquid with a characteristic odour. EtOH is a versatile solvent and is miscible with water and many organic components. Due to its polar character EtOH can dissolve many ionic compounds. EtOH burns with an almost invisible flame.

Ethanol is used as a fuel, alcoholic beverage, as a chemical (e.g. as solvent) or as a feedstock. EtOH is also deliquescent, therefore without proper conditions, it attracts water while stored. Another important feature of EtOH is the formation of an azeotropic mixture with water.

See pages 2 & 3 for Production Process and State of the Art.

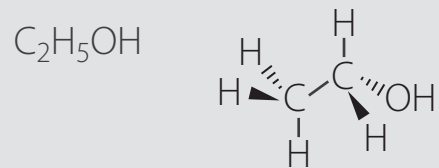
Major stakeholders

The major bioethanol stakeholders in the EU are listed below:

Abengoa Bioenergy, Spain
 Tereos, France
 CropEnergies, Germany
 Cristal Union, France
 Agrana Group, Austria
 Verbio, Germany
 Agroetanol, Sweden
 Industria Meridionale Alcolici, Italy
 AlcoBioFuel, Belgium
 N.prior bioenergy, Germany
 Chemtex, Mossi & Ghisolfi Group, Italy
 DONG Energy, Denmark

Abengoa Bioenergy, a biofuels subsidiary of the Abengoa group, is the European leader of fuel bioethanol production. In 2008, its production capacity was equal to 780 Ml/yr, 580 of which was distributed on the EU market. In the same year, the French industrial group Tereos registered a total production capacity of 770 Ml/yr while the German group CropEnergies reached a total production capacities of 760 Ml/yr.

Molecular Formula



Properties of ethanol

Molecular mass: 46.07 g/mol
 C (%wt) 52.2
 H (%wt) 13.1
 O (%wt) 34.7
 Density at 20°C: 794 kg/cm³
 Viscosity at 20°C: 1.2 mPa s
 Heating value: 26.8 MJ/kg

Utilization

Substitute for petrol; petrol blend component; feedstock for petrol additive ETBE

Relevant fuel regulations

EN 228, EN 15736

Main feedstocks

Sugar and starch from agricultural crops, (sugar cane, cereals, sugar beets); lignocellulosic biomass (forestry residues, agricultural residues, energy crops)

Scale of Production

Industrial production for first-generation ethanol and pilot-plant/demonstration scale for second generation (cellulosic) ethanol

Costs and GHG Balance

Origin	GHG [g CO ₂ eq/km]	Production cost [€/GJ]
Sugar beet, pulp to fodder	160	17.1
Farmed wood	156	21.3
Wheat straw	155	26.6

Assumes crude oil at 50 US-\$/bbl

Production process

EtOH is a naturally widespread chemical, produced by ripe fruits and by wild yeasts or bacteria through fermentation. Ethanol from biomass, usually referred to as bioethanol, can be produced from any feedstock containing appreciable amounts of sugar or materials that can be converted into sugar. The fermentation of such materials has been known for centuries. The first production of pure EtOH was carried out in the Middle East, where the distillation process was reportedly perfected in the 9th century AD. The word "alcohol", commonly used for EtOH, is said to be derived from Arabic. Today fermentation is still the predominate pathway for EtOH production.

Biomass can also be converted to EtOH via biotechnological and thermochemical pathways.

Biochemical pathways

Most EtOH is produced by fermentation from various sugar and starch materials. The most common raw material are sugar cane and corn, and in temperate climates also sugar beet, wheat or potatoes.

The overall fermentation process starting from glucose is

$$C_6H_{12}O_6 \rightleftharpoons 2 C_2H_5OH + 2 CO_2$$

Naturally, the underlying biochemical processes are much more complicated. Adapted yeasts, for example *Saccharomyces cerevisiae* are used and fermentation can be carried out with or without the presence of oxygen. With oxygen some yeasts are prone to respiration, the conversion of sugars to carbon dioxide and water. As EtOH is a toxin, there is a limit to the maximum concentration in the brew produced by the yeasts, some 15 vol.-%, although with specially adapted yeasts up to 20 vol.-% is possible. This results in a high energy demand for EtOH purification by distillation.

In industrial processes an efficiency of about 90 to 95% of theoretical yields can be reached. But, unmodified yeast will only convert sugars with 6 carbon atoms. As sugars with 6 carbon atoms are only a part of the biomass the overall conversion efficiency is much lower. To enable the use of a wider range of biomass components, processes, that also convert sugars with 5 carbon atoms are under development. Larger compounds in biomass must first be broken down into fermentable sugars and lignin which is currently not a candidate feedstock for EtOH.

Other pathways

Non-biotechnological methods for production of EtOH have been developed. EtOH from chemical conversion routes is called synthetic ethanol. The most common chemical process for EtOH production is the acid-catalyzed hydration of ethylene:



Ethylene is obtained from petrochemical feedstocks. Phosphoric acid is mostly used as catalyst. Such production was carried out on an industrial scale in the USA in the 1930s. The ethanol, thus produced, was used industrially, e.g. in solvents, paints and pharmaceuticals. Due to EtOH monopolies imposed by countries such as Germany, chemical ethanol synthesis became less important after the late 1940s

EtOH can also be produced from synthesis gas through chemical synthesis. In addition certain microorganisms are able to digest synthesis gas to produce Ethanol.

EC-funded projects on ethanol

BIOLYFE - Demonstrating large-scale bioethanol production from lignocellulosic feedstocks

NEMO - Novel high-performance enzymes and micro-organisms for conversion of lignocellulosic biomass to bioethanol

DISCO - Targeted DISCOvery of novel cellulases and hemicellulases and their reaction mechanisms for hydrolysis of lignocellulosic biomass (FP7)

BABETHANOL - New feedstock and innovative transformation process for a more sustainable development and production of lignocellulosic ethanol

PROETHANOL2G - Integration of biology and engineering into an economical and energy-efficient 2G bioethanol biorefinery

HYPE - High efficiency consolidated bioprocess technology for lignocellulosic ethanol

KACELLE - Demonstrating industrial scale second generation bioethanol production – Kalundborg cellulosic ethanol plant

FIBRETOH - Bioethanol from paper fibres separated from solid waste, MSW

LED - Lignocellulosic ethanol demonstration

See page 3 for 'State of the Art'

State of the Art

Today huge amounts of EtOH are produced both on an industrial scale and on a small scale. Because of the many methods of EtOH production, statistical data is not always reliable.

Global bioethanol production in 2009 has been estimated at 73,954 MI. The United States is the leading producer with 40,130 MI (54%), while Brazil produced 24,900 MI (34%). The EU-27, with a production of 3,703 MI (5%), ranks third behind these two majors producers.

The production of EtOH by fermentation is a centuries old process but as with every industrial process it is always under optimisation, especially to improve energy use.

As a alternative to using sugar- and/or starch-based biomass, R&D is focused on advanced processes that use lignocellulosic materials as feedstocks. These processes have the potential to increase variety and quantity of suitable feedstocks including cellulosic and food-processing wastes, corn stovers, and cereal straws as well as dedicated fast-growing plants such as poplar trees and switch-grasses. Moreover, cellulosic feedstocks may be grown on non-arable land (limiting competition with the food-chain) and/or be produced from integrated crops (increasing land availability considerably). Advanced processes include biomass pre-treatment to release cellulose and hemicellulose, hydrolysis to fermentable 5- and 6-carbon sugars, sugar fermentation, thermal conversion of solid residues and non-hydrolysed cellulose, and distillation of ethanol to fuel grade. In order to provide better conversions, new pretreatment schemes and innovative enzymatic processes have been investigated.

Since the early 1980s, many processes for this type of conversion have been tested or developed. One of the more sophisticated solutions is the so-called "lignocellulosic feedstock biorefinery (LCF biorefinery)" which uses lignocellulosic biomass, for example wood from short rotation forestry or energy crops like triticale. Besides EtOH, in theory, a broad range of intermediate chemicals could be produced from a LCF biorefinery.

Today in Europe some pilot or demonstration plants are running or are being commissioned. Due to significant investments in funding by the EU and by industry the

technology for production of lignocellulosic biomass to EtOH is available, but market incentives for industrial production are still needed.

Thanks to its properties, EtOH has a series of technical advantages as a fuel for spark-ignition engines. First, EtOH has a very high octane number. This gives the fuel a strong resistance to knock which translates into the possibility of optimizing the engine by increasing compression ratio and advancing spark. Secondly, EtOH has a high heat of vaporization, enabling a cooling effect. This enhances the cylinder filling efficiency, partly offsetting its lower energy content per litre. Finally, the presence of oxygen in the ethanol molecule provides a more homogeneous fuel-air mix formation and permits low-temperature combustions with a consequent decrease in unburned or partially burned molecule emissions (HC, CO, and NOx).

Despite these advantages, some negative properties have also to be considered. Firstly, the oxygen content leads to an increase in the fuel volumetric consumption and, due to its ability to oxidize into acetic acid, may cause compatibility issues with some materials used in the engine, such as metals or polymers. Secondly, the high latent heat of vaporization can cause running difficulties in cold conditions, especially cold start. Finally, EtOH leads to azeotropes with light hydrocarbon fractions and can cause volatility issues. It is miscible with water, which can cause demixing issues when blended with hydrocarbons, and implies acetaldehyde emissions.

Applications

E5 ethanol-gasoline blends can generally be used in conventional spark-ignition engines with no technical changes. E10 can be used in the majority of modern car fleets in EU (vehicle owners should check with specific manufacturers), while modern flexi-fuel vehicles (FFV) can run on up to 85% (E85) with just a few modifications during production. The use of alcohol fuels, such as E95, in heavy duty applications is also possible, with some modified buses and trucks already on the market.

Further information

Up-to-date information on ethanol is available on the European Biofuels Technology Platform website www.biofuelstp.eu