Biofuel

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Biofuels are a wide range of fuels which are in some way derived from biomass. The term covers solid biomass, liquid fuels and various biogases.[1] Biofuels are gaining increased public and scientific attention, driven by factors such as oil price spikes, the need for increased energy security, and concern over greenhouse gas emissions from fossil fuels.

Bioethanol is an alcohol made by fermenting the sugar components of plant materials and it is made mostly from sugar and starch crops. With advanced technology being developed, cellulosic biomass, such as trees and grasses, are also used as feedstocks for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil.

Biodiesel is made from vegetable oils, animal fats or recycled greases. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe.

Biofuels provided 1.8% of the world's transport fuel in 2008. Investment into biofuels production capacity exceeded $4 billion worldwide in 2007 and is growing.[2]

Information on pump regarding ethanol fuel blend up to 10%, California.

Bus run on biodiesel.

Renewable energy

Biofuel
Biomass
Geothermal
Hydroelectricity
Solar energy
Tidal power
Wave power
Wind power

Contents

Liquid fuels for transportation

Most transportation fuels are liquids, because vehicles usually require high energy density, as occurs in liquids and solids. High power density can be provided most inexpensively by an internal combustion engine; these

engines require clean burning fuels, to keep the engine clean and minimize air pollution.

The fuels that are easiest to burn cleanly are typically liquids and gases. Thus liquids (and gases that can be stored in liquid form) meet the requirements of being both portable and clean burning. Also, liquids and gases can be pumped, which means handling is easily mechanized, and thus less laborious.

First generation biofuels

'First-generation biofuels' are biofuels made from sugar, starch, and vegetable oil.

Bioalcohols

Main article: Alcohol fuel

Neat ethanol on the left (A), gasoline on the right (G) at a filling station in Brazil.

Biologically produced alcohols, most commonly ethanol, and less commonly propanol and butanol, are produced by the action of microorganisms and enzymes through the fermentation of sugars or starches (easiest), or cellulose (which is more difficult). Biobutanol (also called biogasoline) is often claimed to provide a direct replacement for gasoline, because it can be used directly in a gasoline engine (in a similar way to biodiesel in diesel engines).

Ethanol fuel is the most common biofuel worldwide, particularly in Brazil. Alcohol fuels are produced by fermentation of sugars derived from wheat, corn, sugar beets, sugar cane, molasses and any sugar or starch that alcoholic beverages can be made from (like potato and fruit waste, etc.). The ethanol production methods used are enzyme digestion (to release sugars from stored starches), fermentation of the sugars, distillation and drying. The distillation process requires significant energy input for heat (often unsustainable natural gas fossil fuel, but cellulosic biomass such as bagasse, the waste left after sugar cane is pressed to extract its juice, can also be used more sustainably).

The Koenigsegg CCXR Edition at the 2008 Geneva Motor Show. This is an "environmentally friendly" version of the CCX, which can use E85 and E100.

Ethanol can be used in petrol engines as a replacement for gasoline; it can be mixed with gasoline to any percentage. Most existing car petrol engines can run on blends of up to 15% bioethanol with petroleum/gasoline. Ethanol has a smaller energy density than gasoline, which means it takes more fuel (volume and mass) to produce the same amount of work. An advantage of ethanol (CH3CH2OH) is that it has a higher octane rating than ethanol-free gasoline available at roadside gas stations which allows an increase of an engine's compression ratio for increased thermal efficiency. In high altitude (thin air) locations, some states mandate a mix of gasoline and ethanol as a winter oxidizer to reduce atmospheric pollution emissions.

Ethanol is also used to fuel bioethanol fireplaces. As they do not require a chimney and are "flueless", bio ethanol fires [3] are extremely useful for new build homes and apartments without a flue. The downside to these fireplaces, is that the heat output is slightly less than electric and gas fires.

In the current alcohol-from-corn production model in the United States, considering the total energy consumed by farm equipment, cultivation, planting, fertilizers, pesticides, herbicides, and fungicides made from petroleum, irrigation systems, harvesting, transport of feedstock to processing plants, fermentation, distillation, drying, transport to fuel terminals and retail pumps, and lower ethanol fuel energy content, the net energy content value added and delivered to consumers is very small. And, the net benefit (all things considered) does little to reduce un-sustainable[*citation needed*] imported oil and fossil fuels required to produce the ethanol.[4]

Although ethanol-from-corn and other food stocks has implications both in terms of world food prices and limited, yet positive energy yield (in terms of energy delivered to customer/fossil fuels used), the technology has led to the development of cellulosic ethanol. According to a joint research agenda conducted through the

U.S. Department of Energy,[5] the fossil energy ratios (FER) for cellulosic ethanol, corn ethanol, and gasoline are 10.3, 1.36, and 0.81, respectively.[6][7][8]

Many car manufacturers are now producing flexible-fuel vehicles (FFV's), which can safely run on any combination of bioethanol and petrol, up to 100% bioethanol. They dynamically sense exhaust oxygen content, and adjust the engine's computer systems, spark, and fuel injection accordingly. This adds initial cost and ongoing increased vehicle maintenance.[*citation needed*] As with all vehicles, efficiency falls and pollution emissions increase when FFV system maintenance is needed (regardless of the fuel mix being used), but is not performed. FFV internal combustion engines are becoming increasingly complex, as are multiple-propulsion-system FFV hybrid vehicles, which impacts cost, maintenance, reliability, and useful lifetime longevity. [*citation needed*]

Even dry ethanol has roughly one-third lower energy content per unit of volume compared to gasoline, so larger / heavier fuel tanks are required to travel the same distance, or more fuel stops are required. With large current unsustainable, non-scalable subsidies, ethanol fuel still costs much more per distance traveled than current high gasoline prices in the United States.[9]

Methanol is currently produced from natural gas, a non-renewable fossil fuel. It can also be produced from biomass as biomethanol. The methanol economy is an interesting alternative to get to the hydrogen economy, compared to today's hydrogen production from natural gas. But this process is not the state-of-the-art clean solar thermal energy process, where hydrogen production is directly produced from water.[10]

Butanol is formed by ABE fermentation (acetone, butanol, ethanol) and experimental modifications of the process show potentially high net energy gains with butanol as the only liquid product. Butanol will produce more energy and allegedly can be burned "straight" in existing gasoline engines (without modification to the engine or car),[11] and is less corrosive and less water soluble than ethanol, and could be distributed via existing infrastructures. DuPont and BP are working together to help develop Butanol. E. coli have also been successfully engineered to produce Butanol by hijacking their amino acid metabolism.[12]

Fermentation is not the only route to forming biofuels or bioalcohols. One can obtain methanol, ethanol, butanol or mixed alcohol fuels through pyrolysis of biomass including agricultural waste or algal biomass. The most exciting of these pyrolysis alcoholic fuels is the pyrolysis biobutanol. The product can be made with limited water use and most places in the world.

Green diesel

Main article: Green diesel

Green diesel, also known as renewable diesel, is a form of diesel fuel which is derived from renewable feedstock rather than the fossil feedstock used in most diesel fuels. Green diesel feedstock can be sourced from a variety of oils including canola, algae, jatropha and salicornia in addition to tallow. Green diesel uses traditional fractional distillation to process the oils, not to be confused with biodiesel which is chemically quite different and processed using transesterification.

“Green Diesel” as commonly known in Ireland should not be confused with dyed green diesel sold at a lower tax rate for agriculture purposes, using the dye allows custom officers to determine if a person is using the cheaper diesel in higher taxed applications such as commercial haulage or cars.[13]

Biodiesel

Main articles: Biodiesel and Biodiesel around the world

Biodiesel is the most common biofuel in Europe. It is produced from oils or fats using transesterification and is a liquid similar in composition to fossil/mineral diesel. Chemically, it consists mostly of fatty acid methyl (or ethyl) esters (FAMEs). Feedstocks for biodiesel include animal fats, vegetable oils, soy, rapeseed, jatropha, mahua, mustard, flax, sunflower, palm oil, hemp, field pennycress, pongamia pinnata and algae. Pure biodiesel (B100) is the lowest emission diesel fuel. Although liquefied petroleum gas and hydrogen have cleaner combustion, they are used to fuel much less efficient petrol engines and are not as widely available.

Biodiesel can be used in any diesel engine when mixed with mineral diesel. In some countries manufacturers cover their diesel engines under warranty for B100 use, although Volkswagen of Germany, for example, asks drivers to check by telephone with the VW environmental services department before switching to B100. B100 may become more viscous at lower temperatures, depending on the feedstock used. In most cases, biodiesel is compatible with diesel engines from 1994 onwards, which use 'Viton' (by DuPont) synthetic rubber in their mechanical fuel injection systems.

In some countries biodiesel is less expensive than conventional diesel.

Electronically controlled 'common rail' and 'unit injector' type systems from the late 1990s onwards may only use biodiesel blended with conventional diesel fuel. These engines have finely metered and atomized multi-stage injection systems that are very sensitive to the viscosity of the fuel. Many current generation diesel engines are made so that they can run on B100 without altering the engine itself, although this depends on the fuel rail design. Since biodiesel is an effective solvent and cleans residues deposited by mineral diesel, engine filters may need to be replaced more often, as the biofuel dissolves old deposits in the fuel tank and pipes. It also effectively cleans the engine combustion chamber of carbon deposits, helping to maintain efficiency. In many European countries, a 5% biodiesel blend is widely used and is available at thousands of gas stations.[14][15] Biodiesel is also an *oxygenated fuel*, meaning that it contains a reduced amount of carbon and higher hydrogen and oxygen content than fossil diesel. This improves the combustion of fossil diesel and reduces the particulate emissions from un-burnt carbon.

Biodiesel is also safe to handle and transport because it is as biodegradable as sugar, 10 times less toxic than table salt, and has a high flash point of about 300 F (148 C) compared to petroleum diesel fuel, which has a flash point of 125 F (52 C).[16]

In the USA, more than 80% of commercial trucks and city buses run on diesel. The emerging US biodiesel market is estimated to have grown 200% from 2004 to 2005. "By the end of 2006 biodiesel production was estimated to increase fourfold [from 2004] to more than 1 billion gallons".[17]

Vegetable oil

Main article: Vegetable oil used as fuel

Straight unmodified edible vegetable oil is generally not used as fuel, but lower quality oil can be used for this purpose. Used vegetable oil is increasingly being processed into biodiesel, or (more rarely) cleaned of water and particulates and used as a fuel.

Also here, as with 100% biodiesel (B100), to ensure that the fuel injectors atomize the vegetable oil in the correct pattern for efficient combustion, vegetable oil fuel must be heated to reduce its viscosity to that of diesel, either by electric coils or heat exchangers. This is easier in warm or temperate climates. Big corporations like MAN B&W Diesel, Wärtsilä and Deutz AG as well as a number of smaller companies such as Elsbett offer engines that are compatible with straight vegetable oil, without the need for after-market modifications.

Vegetable oil can also be used in many older diesel engines that do not use common rail or unit injection electronic diesel injection systems. Due to the design of the combustion chambers in indirect injection engines, these are the best engines for use with vegetable oil. This system allows the relatively larger oil molecules more time to burn. Some older engines, especially Mercedes are driven experimentally by enthusiasts without any conversion, a handful of drivers have experienced limited success with earlier pre-"Pumpe Duse" VW TDI engines and other similar engines with direct injection. Several companies like Elsbett or Wolf have developed professional conversion kits and successfully installed hundreds of them over the last decades.

Oils and fats can be hydrogenated to give a diesel substitute. The resulting product is a straight chain hydrocarbon, high in cetane, low in aromatics and sulfur and does not contain oxygen. Hydrogenated oils can be blended with diesel in all proportions Hydrogenated oils have several advantages over biodiesel, including

good performance at low temperatures, no storage stability problems and no susceptibility to microbial attack.[18]

Bioethers

Bio ethers (also referred to as fuel ethers or oxygenated fuels) are cost-effective compounds that act as octane rating enhancers. They also enhance engine performance, whilst significantly reducing engine wear and toxic exhaust emissions. Greatly reducing the amount of ground-level ozone, they contribute to the quality of the air we breathe.[19][20]

Biogas

Filtered waste vegetable oil.

Main article: Biogas

Biogas is methane produced by the process of anaerobic digestion of organic material by anaerobes.[21] It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. The solid byproduct, digestate, can be used as a biofuel or a fertilizer.

Pipes carrying biogas

- Biogas can be recovered from mechanical biological treatment waste processing systems.

  Note:Landfill gas is a less clean form of biogas which is produced in landfills through naturally occurring anaerobic digestion. If it escapes into the atmosphere it is a potential greenhouse gas.

- Farmers can produce biogas from manure from their cows by getting a anaerobic digester (AD).[22]

Syngas

Main article: Gasification

Syngas, a mixture of carbon monoxide and hydrogen, is produced by partial combustion of biomass, that is, combustion with an amount of oxygen that is not sufficient to convert the biomass completely to carbon dioxide and water.[18] Before partial combustion the biomass is dried, and sometimes pyrolysed. The resulting gas mixture, syngas, is more efficient than direct combustion of the original biofuel; more of the energy contained in the fuel is extracted.

- Syngas may be burned directly in internal combustion engines or turbines. The wood gas generator is a wood-fueled gasification reactor mounted on an internal combustion engine.
- Syngas can be used to produce methanol, DME and hydrogen, or converted via the Fischer-Tropsch process to produce a diesel substitute, or a mixture of alcohols that can be blended into gasoline.

Gasification normally relies on temperatures >700°C.
- Lower temperature gasification is desirable when co-producing biochar but results in a Syngas polluted with tar.

Solid biofuels

Examples include wood, sawdust, grass cuttings, domestic refuse, charcoal, agricultural waste, non-food energy crops (see picture), and dried manure.

When raw biomass is already in a suitable form (such as firewood), it can burn directly in a stove or furnace to provide heat or raise steam. When raw biomass is in an inconvenient form (such as sawdust, wood chips, grass, urban waste wood, agricultural residues), the typical process is to densify the biomass. This process includes grinding the raw biomass to an appropriate particulate size (known as hogfuel), which depending on the densification type can be from 1 to 3 cm (1 in), which is then concentrated into a fuel product. The current types of processes are wood pellet, cube, or puck. The pellet process is most common in Europe and is typically a pure wood product. The other types of densification are larger in size compared to a pellet and are compatible with a broad range of input feedstocks. The resulting densified fuel is easier to transport and feed into thermal generation systems such as boilers.

A problem with the combustion of raw biomass is that it emits considerable amounts of pollutants such as particulates and PAHs (polycyclic aromatic hydrocarbons). Even modern pellet boilers generate much more pollutants than oil or natural gas boilers. Pellets made from agricultural residues are usually worse than wood pellets, producing much larger emissions of dioxins and chlorophenols.[23]

Notwithstanding the above noted study, numerous studies have shown that biomass fuels have significantly less impact on the environment than fossil based fuels. Of note is the U.S. Department of Energy Laboratory, Operated by Midwest Research Institute Biomass Power and Conventional Fossil Systems with and without CO2 Sequestration – Comparing the Energy Balance, Greenhouse Gas Emissions and Economics Study. Power generation emits significant amounts of greenhouse gases (GHGs), mainly carbon dioxide (CO_2). Sequestering CO_2 from the power plant flue gas can significantly reduce the GHGs from the power plant itself, but this is not the total picture. CO_2 capture and sequestration consumes additional energy, thus lowering the plant's fuel-to-electricity efficiency. To compensate for this, more fossil fuel must be procured and consumed to make up for lost capacity.

Taking this into consideration, the global warming potential (GWP), which is a combination of CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions, and energy balance of the system need to be examined using a life cycle assessment. This takes into account the upstream processes which remain constant after CO_2 sequestration as well as the steps required for additional power generation. firing biomass instead of coal led to a 148% reduction in GWP.

A derivative of solid biofuel is biochar, which is produced by biomass pyrolysis. Bio-char made from agricultural waste can substitute for wood charcoal. As wood stock becomes scarce this alternative is gaining ground. In eastern Democratic Republic of Congo, for example, biomass briquettes are being marketed as an alternative to charcoal in order to protect Virunga National Park from deforestation associated with charcoal production.[24]

Second generation biofuels

Main article: Second generation biofuels

Supporters of biofuels claim that a more viable solution is to increase political and industrial support for, and rapidity of, second-generation biofuel implementation from non-food crops. These include waste biomass, the stalks of wheat, corn, wood, and special-energy-or-biomass crops (e.g. Miscanthus). Second generation (2G) biofuels use biomass to liquid technology,[25] including cellulosic biofuels.[26] Many second generation biofuels are under development such as biohydrogen, biomethanol, DMF, BioDME, Fischer-Tropsch diesel, biohydrogen diesel, mixed alcohols and wood diesel.

Cellulosic ethanol production uses non-food crops or inedible waste products and does not divert food away from the animal or human food chain. Lignocellulose is the "woody" structural material of plants. This

feedstock is abundant and diverse, and in some cases (like citrus peels or sawdust) it is in itself a significant disposal problem.

Producing ethanol from cellulose is a difficult technical problem to solve. In nature, ruminant livestock (like cattle) eat grass and then use slow enzymatic digestive processes to break it into glucose (sugar). In cellulosic ethanol laboratories, various experimental processes are being developed to do the same thing, and then the sugars released can be fermented to make ethanol fuel. In 2009 scientists reported developing, using "synthetic biology", "15 new highly stable fungal enzyme catalysts that efficiently break down cellulose into sugars at high temperatures", adding to the 10 previously known.[27] The use of high temperatures, has been identified as an important factor in improving the overall economic feasibility of the biofuel industry and the identification of enzymes that are stable and can operate efficiently at extreme temperatures is an area of active research.[28] In addition, research conducted at TU Delft by Jack Pronk has shown that elephant yeast, when slightly modified can also create ethanol from non-edible ground sources (e.g. straw).[29][30]

The recent discovery of the fungus Gliocladium roseum points toward the production of so-called myco-diesel from cellulose. This organism was recently discovered in the rainforests of northern Patagonia and has the unique capability of converting cellulose into medium length hydrocarbons typically found in diesel fuel.[31] Scientists also work on experimental recombinant DNA genetic engineering organisms that could increase biofuel potential.

Scientists working in New Zealand have developed a technology to use industrial waste gases from steel mills as a feedstock for a microbial fermentation process to produce ethanol.[32][33]

Second, third, and fourth generation biofuels are also called advanced biofuels.

Third generation biofuels

Main article: Algae fuel

Algae fuel, also called oilgae or third generation biofuel, is a biofuel from algae. Algae are low-input, high-yield feedstocks to produce biofuels. Based on laboratory experiments, it is claimed that algae can produce up to 30 times more energy per acre than land crops such as soybeans,[34] but these yields have yet to be produced commercially. With the higher prices of fossil fuels (petroleum), there is much interest in algaculture (farming algae). One advantage of many biofuels over most other fuel types is that they are biodegradable, and so relatively harmless to the environment if spilled.[35][36][37] Algae fuel still has its difficulties though, for instance to produce algae fuels it must be mixed uniformly, which, if done by agitation, could affect biomass growth.[38]

The United States Department of Energy estimates that if algae fuel replaced all the petroleum fuel in the United States, it would require only 15,000 square miles (38,849 square kilometers), which is roughly the size of Maryland,[34] or less than one seventh the amount of land devoted to corn in 2000.[39]

Algae, such as *Botryococcus braunii* and *Chlorella vulgaris* are relatively easy to grow,[40] but the algal oil is hard to extract. There are several approaches, some of which work better than others.[41] Macroalgae (seaweed) also have a great potential for bioethanol and biogas production.[42]

Ethanol from living algae

Most biofuel production comes from harvesting organic matter and then converting it to fuel but an alternative approach relies on the fact that some algae naturally produce ethanol and this can be collected without killing the algae. The ethanol evaporates and then can be condensed and collected. The company Algenol is trying to commercialize this process.

Fourth generation biofuels

A number of companies are pursuing advanced "bio-chemical" and "thermo-chemical" processes that produce "drop in" fuels like "green gasoline," "green diesel," and "green aviation fuel." While there is no one established definition of "fourth-generation biofuels," some have referred to it as the biofuels created from processes other

than first generation ethanol and biodiesel, second generation cellulosic ethanol, and third generation algae biofuel. Some fourth generation technology pathways include: pyrolysis, gasification, upgrading, solar-to-fuel, and genetic manipulation of organisms to secrete hydrocarbons.[43]

- GreenFuel Technologies Corporation developed a patented bioreactor system that uses nontoxic photosynthetic algae to take in smokestacks flue gases and produce biofuels such as biodiesel, biogas and a dry fuel comparable to coal.[44]
- With thermal depolymerization of biological waste one can extract methane and other oils similar to petroleum.

Hydrocarbon plants or petroleum plants are plants which produce terpenoids as secondary metabolites that can be converted to gasoline-like fuels. Latex producing members of the Euphorbiaceae such as *Euphorbia lathyris* and *E. tirucalli* and members of Apocynaceae have been studied for their potential energy uses.[45][46]

Green fuels

However, if biocatalytic cracking and traditional fractional distillation are used to process properly prepared algal biomass i.e. biocrude,[47] then as a result we receive the following distillates: jet fuel, gasoline, diesel, etc.. Hence, we may call them third generation or green fuels.

Biofuels by region

Main article: Biofuels by region

There are international organizations such as IEA Bioenergy,[48] established in 1978 by the OECD International Energy Agency (IEA), with the aim of improving cooperation and information exchange between countries that have national programs in bioenergy research, development and deployment. The U.N. International Biofuels Forum is formed by Brazil, China, India, South Africa, the United States and the European Commission.[49] The world leaders in biofuel development and use are Brazil, United States, France, Sweden and Germany.

See also: Biodiesel around the world

Issues with biofuel production and use

Main article: Issues relating to biofuels

There are various social, economic, environmental and technical issues with biofuel production and use, which have been discussed in the popular media and scientific journals. These include: the effect of moderating oil prices, the "food vs fuel" debate, poverty reduction potential, carbon emissions levels, sustainable biofuel production, deforestation and soil erosion, loss of biodiversity, impact on water resources, as well as energy balance and efficiency.

See also

- Aviation biofuel
- BioEthanol for Sustainable Transport
- Biofuels Center of North Carolina
- Biofuelwatch
- Biogas powerplant
- Bioheat, a biofuel blended with heating oil.
- Biomass briquettes
- Cellulosic ethanol
- Clean Cities (U.S. DOE Program to increase the use of all the alternative fuels, including the prominent biofuels biodiesel and ethanol)
- Biomass to liquid bio-oil
- Dimethyl ether
- Energy forestry

- Ecological sanitation
- Energy content of biofuel
- Green crude
- Green Earth Technologies
- IRENA
- Life cycle assessment
- List of biofuel companies and researchers
- List of emerging technologies
- List of vegetable oils section on oils used as biodiesel
- Low-carbon economy
- Sustainable transport
- Table of biofuel crop yields
- Vegetable oil economy

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- Fuel Quality Directive Impact Assessment
- Biofuels Journal
- James Smith (November 2010). *Biofuels and the Globalisation of Risk*. [Zed Books]. ISBN 9781848135727. http://www.zedbooks.co.uk/book.asp?bookdetail=4363.

External links

- Alternative Fueling Station Locator (EERE).
- Towards Sustainable Production and Use of Resources: Assessing Biofuels by the United Nations Environment Programme, October 2009.
- Biofuels guidance for businesses, including permits and licences required on NetRegs.gov.uk
- How Much Water Does It Take to Make Electricity? -- Natural gas requires the least water to produce energy, some biofuels the most, according to a new study.

- International Conference on Biofuels Standards - European Union Biofuels Standardization
- International Energy Agency: Biofuels for Transport - An International Perspective
- Biofuels from Biomass: Technology and Policy Considerations Thorough overview from MIT
- The Guardian news on biofuels
- The U.S. DOE Clean Cities Program - links to all of the Clean Cities coalitions that exist throughout the U.S. (there are 87 of them)

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