CLARIANT

Communication Dossier
sunliquid®
CONVERTS STRAW INTO BIOFUEL

what is precious to you?

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Product description

The sunliquid® process developed by Clariant converts previously unusable plant residues like cereal straw, corn stover or bagasse almost completely into the high-quality biofuel ethanol. The process consists of several steps: first, the plant residues are crushed mechanically and thermally pretreated. Then, microorganisms tailored to each raw material very rapidly produce a large amount of enzymes that break down the straw constituents cellulose and hemicellulose into three different types of sugar. This sugar is fermented using specially developed fermentation organisms and thus converted to ethanol.

Customer benefits

The sunliquid® process can be used flexibly for the different regionally available raw materials. The integrated enzyme production, for example, offers considerable price advantages and makes the process independent of enzyme suppliers. Using enzymes tailored individually to the raw material and the process conditions, the second process step – the breakdown of cellulose and hemicellulose into individual sugars – proceeds much more efficiently than with standard enzymes. Unlike conventional processes, sunliquid® can handle all types of sugars, and thus yields about 50% more ethanol than previous processes. The process is also energy self-sufficient. The entire process energy originates from the utilization of lignin obtained as a residue. This is made possible by the newly developed ethanol purification with adsorbers, which requires up to 50% less energy than conventional distillation. The sunliquid® process is also flexible and adaptable to our customers' specific needs.

Environmental benefits

Cellulosic ethanol produced with sunliquid® reduces greenhouse gas emissions by about 95% compared to gasoline, and no fossil resources are needed. The biomass needed as raw material does not have to be grown but is obtained as a residue in food production. sunliquid® bioethanol is therefore not produced in competition with human food or animal feed and also does not require additional cultivation areas. Since no further energy is needed for the process, its emission profile is considerably better than that of conventional bioethanol production. Its water consumption is also very low due to efficient recycling.

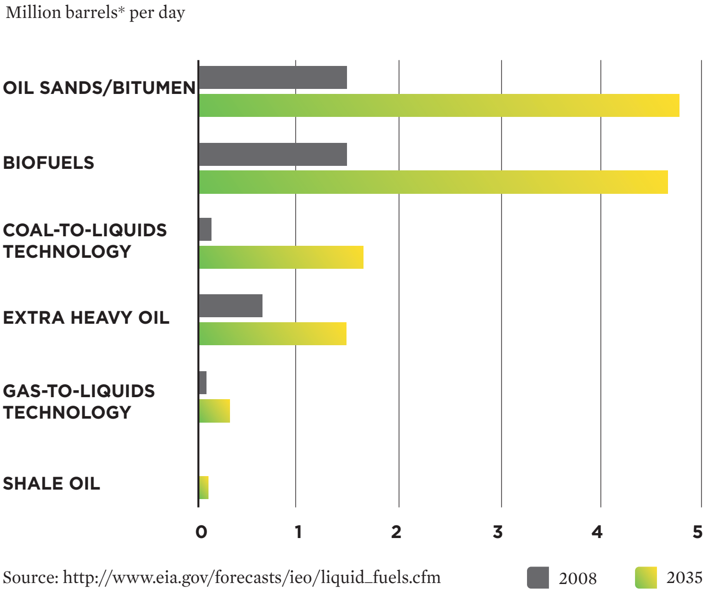
Economic benefits

The world market for bioethanol is growing rapidly as it is being promoted by the regulatory framework conditions e.g. in the USA and European Union. The anticipated price increases for crude oil based fuels are also generating strong impulses in favor of bioethanol. Moreover, ethanol plants reduce dependence on imported fossil resources and create regional employment. Equally, the demand for bioethanol and other bio-based chemicals is growing in the chemical industry in the light of dwindling fossil raw materials and increasingly stringent sustainability requirements. Clariant is therefore anticipating a very strong increase in demand both for bioethanol and the sunliquid® process.

Not only the rising gasoline prices are a clear indicator: fossil fuels are gradually running out. More and more countries are seeking to reduce their dependence on the oil exporting nations. Climate change is also making itself increasingly felt. In the light of these developments, sustainable alternatives are called for, especially in the traffic sector which consumes around 50% of global crude oil production. These alternatives include biofuels such as biomass-based fuels like bioethanol produced, for example, from cereal, corn or sugar cane.

Previously, only the infructescences of these agricultural plants, in other words the parts also used as food, could be converted into bioethanol. The rest of the produced biomass remained unused. However, the woody parts of the plants also contain valuable sugars and can in principle also be converted to ethanol. But as this sugar is bound in fibrous lignocellulose, it is difficult to access. Only the newly developed biotechnology process sunliquid® has succeeded in converting the straw into biofuel as well and making it economically useful.

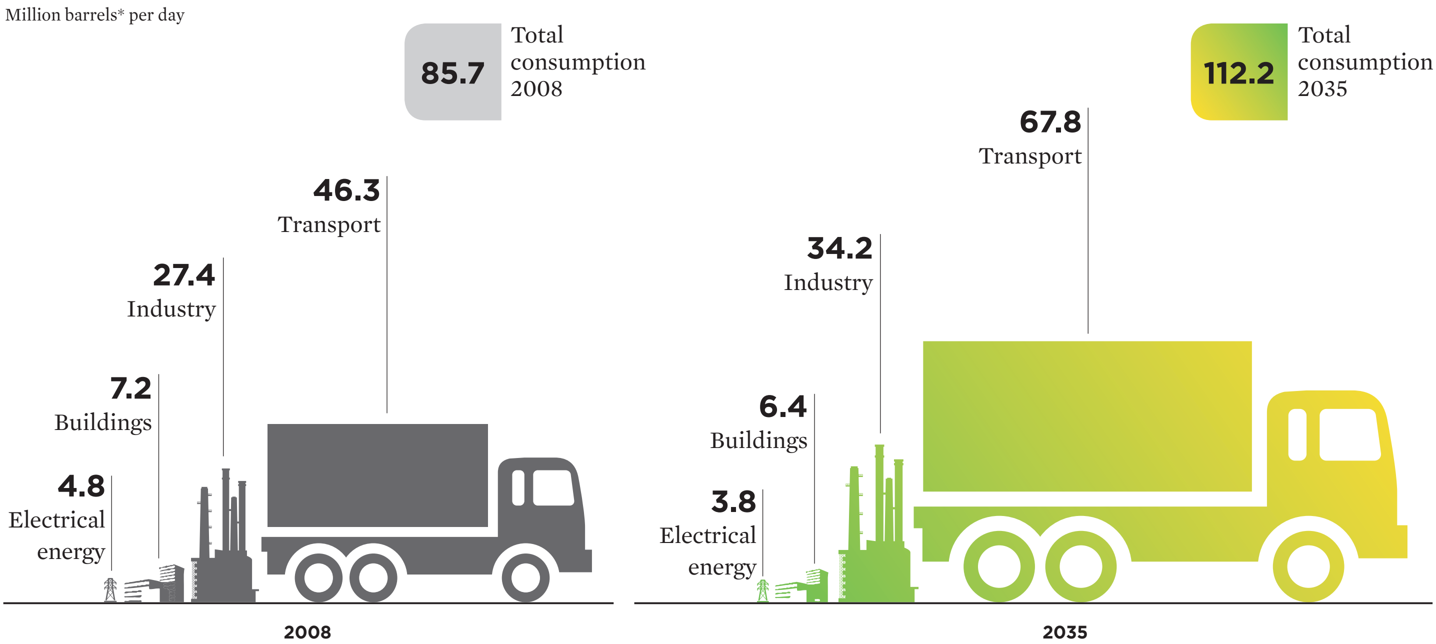
UNCONVENTIONAL LIQUID FUEL PRODUCTION BY TYPE OF FUEL WORLDWIDE 2008 AND 2035



Source: http://www.eia.gov/forecasts/ieo/liquid_fuels.cfm

*1 barrel (abbreviated bl) = 119.24 liters.

WORLD LIQUID FUEL CONSUMPTION 2008 AND 2035



Source: http://www.eia.gov/forecasts/ieo/liquid_fuels.cfm

The sunliquid® process is a biological method for converting agricultural residues into bioethanol, also known as cellulosic ethanol. This bioethanol can be used as automobile fuel or as a feedstock for the chemical industry. The sunliquid® process can utilize agricultural residues on a regional basis: e.g. corn stover in North America, bagasse in South America or wheat straw in Europe. For example, about 300 million tons of straw are produced in the 27 member states of the European Union, up to 60% of which would theoretically be available for ethanol production. This would cover about 25% of the EU gasoline demand in 2020.

In 2012, Germany's first and so far largest demonstration plant for cellulosic ethanol came on stream in Straubing in Bavaria – a milestone in the development of the sunliquid® technology. The plant has an annual output of 1,000 tons and was designed to establish and further optimize the sunliquid® process on an industrial scale. Commercial plants will later be producing 50,000 to 150,000 tons of bioethanol a year, thereby contributing to making the world's fuel supply more sustainable, climate friendly and safe.

»With the sunliquid® process, Clariant has succeeded in converting difficult to access sugars from previously unusable plant residues like cereal straw, corn stover or bagasse almost completely into high quality ethanol. The process has the potential to revolutionize the bioethanol market.«

–
PROF. DR. ANDRE KOLTERMANN,
Head Biotech & Renewables Center at Clariant

MAIN LIGNOCELLULOSIC FEEDSTOCKS IN DIFFERENT REGIONS OF THE WORLD

WHEAT STRAW

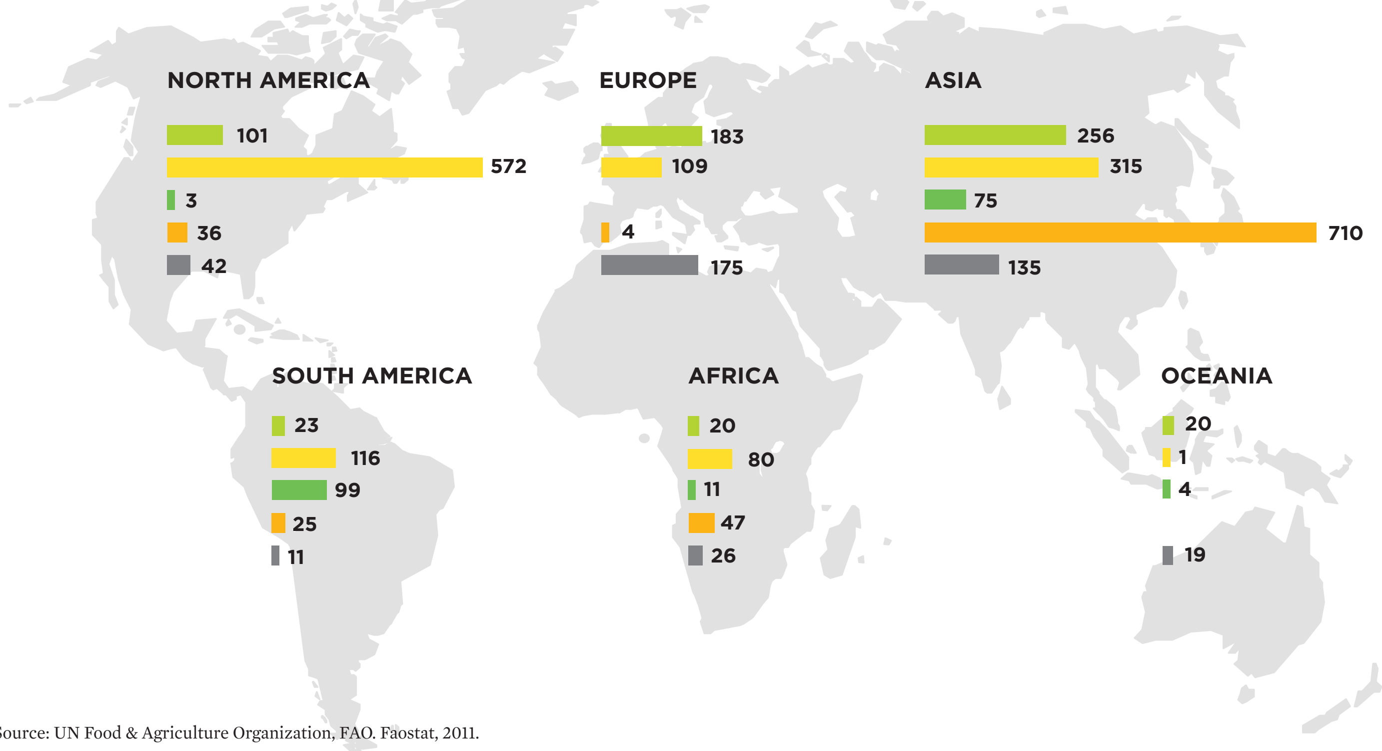
CORN STOVER

BAGASSE

RICE STRAW

OTHER CEREAL STRAW

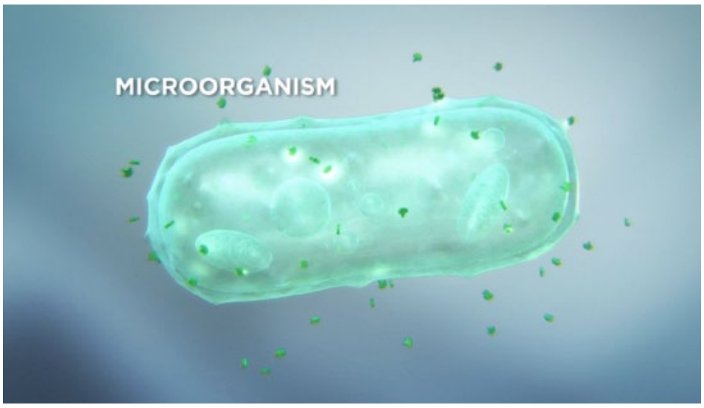
In million tons



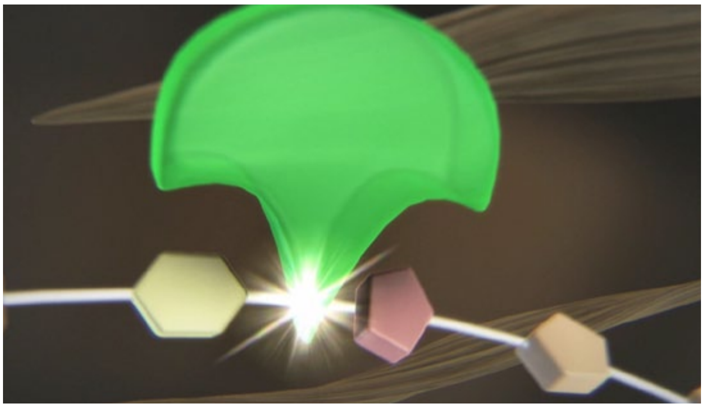
Source: UN Food & Agriculture Organization, FAO. Faostat, 2011.

The sunliquid® process consists of four technological subprocesses. The straw is first crushed and thermally pretreated to open up the stable lignocellulose structure and make it easier for the enzymes to access to the sugar chains. The straw fibers are then divided into two batches: a very small amount is exposed to special microorganisms which use the straw as a nutrient base and very rapidly produce a large amount of raw material- and process-specific enzymes – a kind of biological scissors that can cut up the long cellulose chains. These enzymes are then added again to the main portion of the raw material. They liquefy the straw and break down its constituents cellulose and hemicellulose into the sugars glucose, xylose and arabinose. Lignin, the woody component, is separated and incinerated to produce energy for the process. Together with the other residue streams, it is the most important source of energy for the largely energy autonomic process.

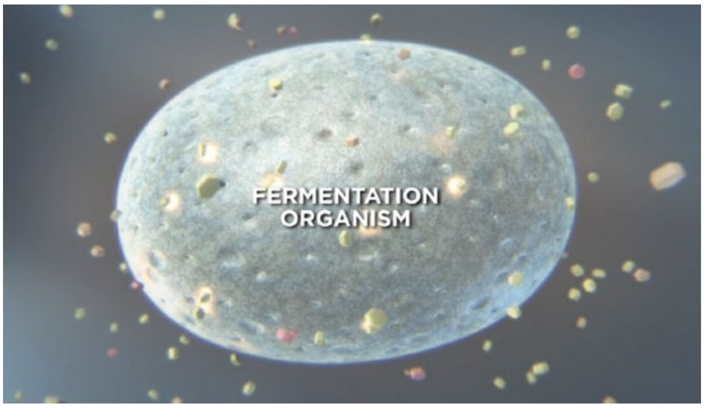
Specially developed fermentation organisms are now added to the resulting sugar solution and convert all types of sugar simultaneously to ethanol, a type of alcohol. In the final step, the water now has to be removed. Instead of the highly energy-consuming distillation, the sunliquid® process uses adsorbers – porous, sponge-like structures that act like sieves – to obtain pure ethanol from the fermentation mixture. While the water passes unhindered through the adsorbers, the ethanol remains adhering to their large surface and is then separated off. The pure ethanol can now be processed further into biofuel.



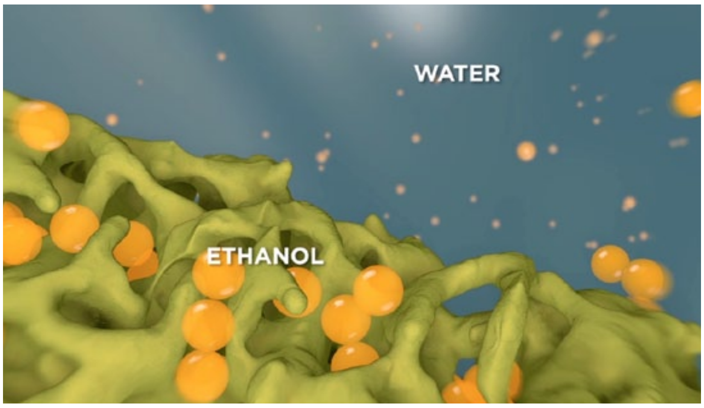
A SMALL AMOUNT OF STRAW FIBERS is used as a nutrient base by microorganisms, which then produce large amounts of raw material- and process-specific enzymes.



THE TAILORED ENZYMES act like a kind of biological scissors that cut up the long sugar chains. They release all the available types of sugar from the straw – the C_6 sugar glucose as well as the C_5 sugars xylose and arabinose.



IN THE NEXT STEP all types of sugar are absorbed simultaneously by specially developed fermentation organisms and converted into ethanol.



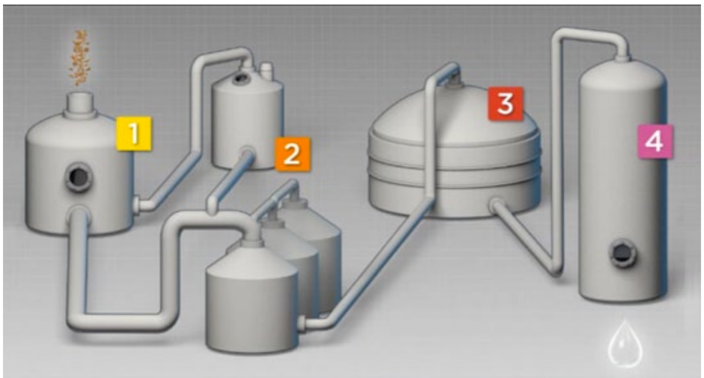
DURING THE PURIFICATION – the separation of water and ethanol – water passes unhindered through special adsorbers, while the ethanol initially remains adhering to their surface and is then separated out.

Previously, enzymes were the most costly single item among the production costs. In the sunliquid® process, enzyme costs are reduced to a minimum by the process-integrated production directly in the facility. Costs of logistics, storage and treatment are eliminated and there is no dependence on enzyme suppliers. Since the enzymes are individually tailored to the raw material and process conditions, the process is also considerably more efficient than when using standard enzymes.

With these optimized enzymes, the process delivers high sugar yields. It can convert not only glucose – the readily degradable C_6 sugar – but also the more difficult to utilize C_5 sugars xylose and arabinose. This increases the ethanol yield by about 50%.

Purification by adsorbers

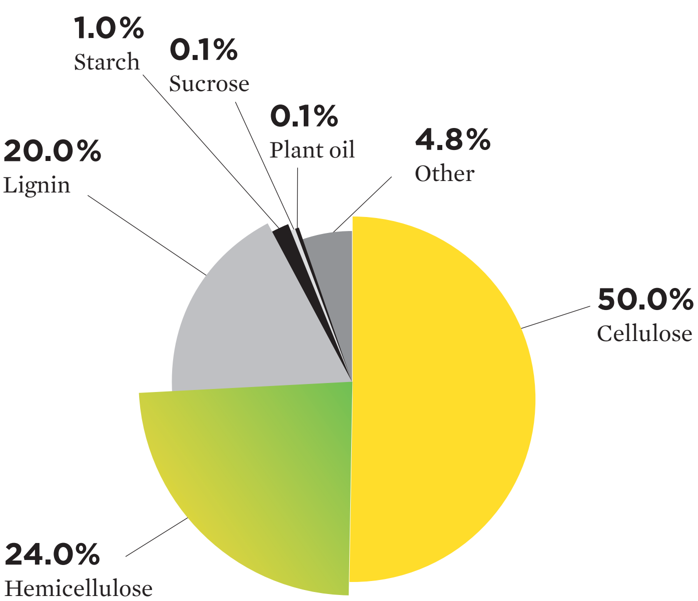
After the fermentation, the ethanol is diluted with water and has to be separated from it. In standard processes, this is done by highly energy-consuming distillation. The sunliquid® process, however, uses adsorbers, porous, sponge-like structures which act like sieves and bind the ethanol. This allows energy savings of up to 50% in this step.



THE SUNLIQUID® PROCESS IS DIVIDED INTO FOUR SUBPROCESSES

1. Mechanical and thermal pretreatment
2. Enzyme production and addition of sugars
3. Fermentation
4. Purification

GLOBAL DISTRIBUTION OF DIFFERENT STRUCTURAL BIOMASS



»The innovative sunliquid® process can reduce dependence on fossil fuels and promote local fuel production because every production facility can use the agricultural residues growing in the region. This creates green jobs and additional income for regional agriculture.«

DR. MARKUS RARBACH,
Head Start-up Business Project
Biofuels & Derivatives, Clariant

Cellulosic ethanol produced by sunliquid® is almost carbon neutral. Taking the total amount of greenhouse gases emitted by gasoline as 100%, then cellulosic ethanol, the second-generation biofuel, saves about 95% of this amount. The emission profile is also much better than that of bioethanol produced from the infructescences of wheat or corn. This first-generation bioethanol saves only between 19 and 78% of gasoline related greenhouse gases.

The biomass needed as raw material for cellulosic ethanol does not have to be grown specially, but is obtained anyway as a by-product of agricultural production. sunliquid® bioethanol is therefore not produced in competition with human food or animal feed and requires no additional crop areas. This eliminates a serious socioethical dilemma, the »food or fuel« competition.

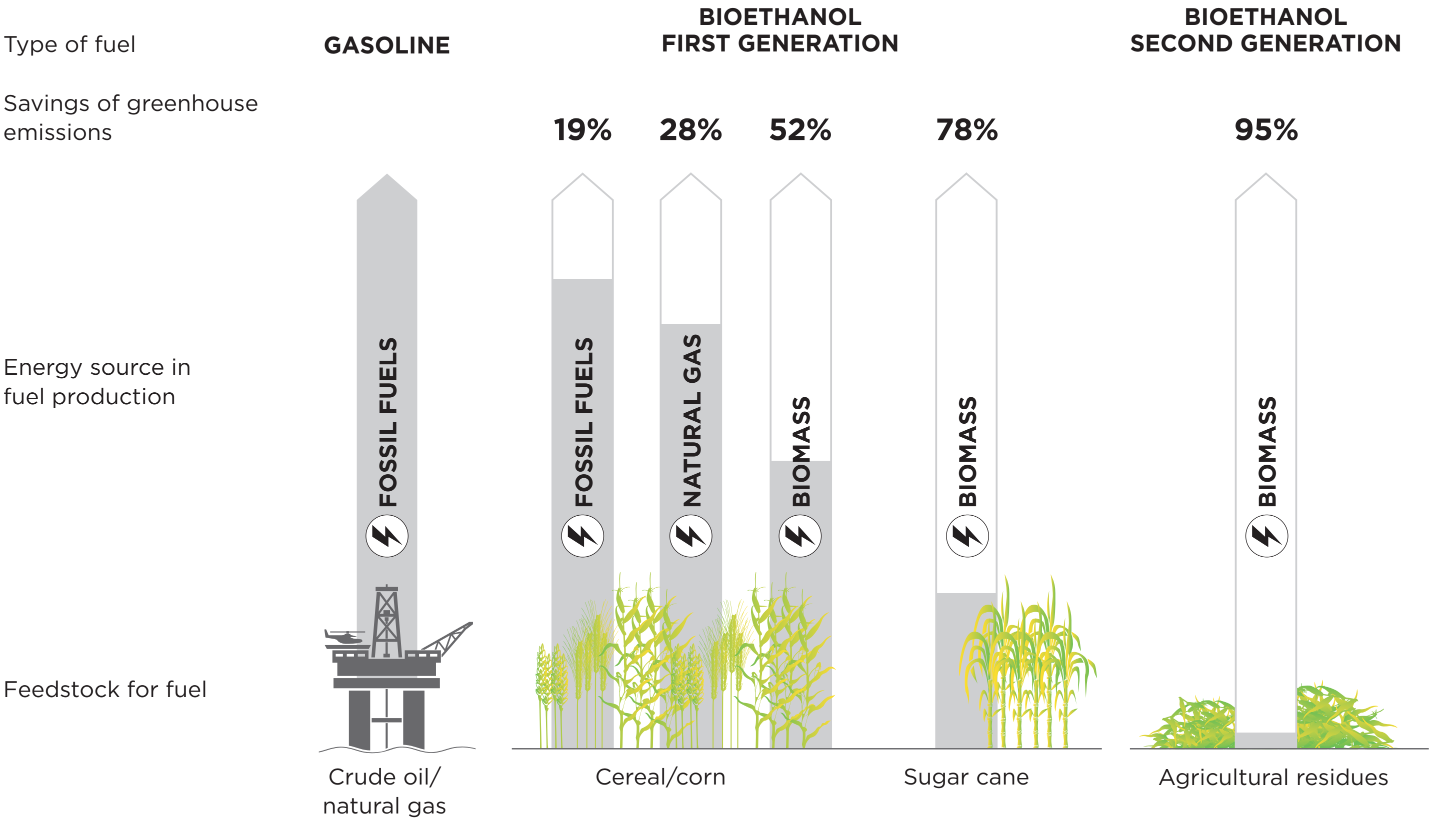
With its adsorber-based method of ethanol purification and the utilization of residues like lignin as the sole energy source, the sunliquid® process is energy self-sufficient and requires no additional input of fossil energy. Its water consumption is also very low due to efficient recycling. The new process also creates additional growth opportunities for rural regions, where biorefineries for cellulosic ethanol and therefore »green jobs« and income could be created for agriculture.

»If we can make the breakthrough here using the sunliquid® technology, it will create a range of new options in terms of jobs and earnings potential especially in rural areas.«

—

MARTIN ZEIL, Bavarian Minister of Economics

SAVINGS OF GREENHOUSE GAS EMISSIONS IN THE PRODUCTION OF VARIOUS BIOFUELS, COMPARED TO GASOLINE



Source: Acc. to Wang et al., Environ. Res. Lett. 2, 2007, 024001.

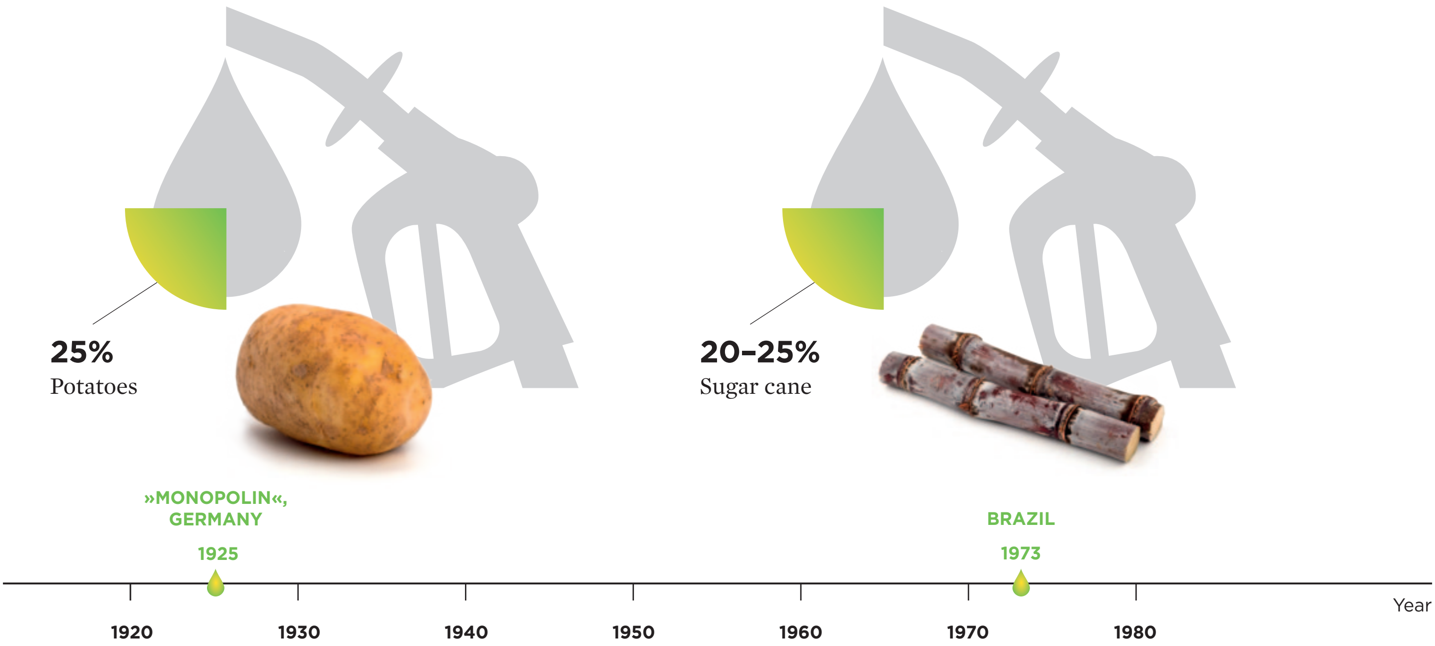
BACKGROUND INFORMATION: SHORT HISTORY OF BIOETHANOL

The use of bioethanol as a fuel is as old as the automobile itself. In 1860, Nicolaus August Otto used ethanol as fuel in the prototypes of his internal combustion engine. Henry Ford, the pioneer of mass motorization, believed that ethanol would be the fuel of the future. The first Ford T models were planned to be powered by ethanol, but the crude oil prices at that time were too low. In Germany in 1925, the »Reichskraftsprit-Gesellschaft mbH« founded in the same year introduced »Monopolin« which contained up to 25% bioethanol produced from potatoes. Over the ensuing decades, crude oil became the dominant energy source.

Only since the oil crisis of 1973 has bioethanol fuel experienced a renewed upswing thanks to the support of various governments, e.g. in Brazil and the USA. In Brazil, an industry for ethanol fuel based on sugar cane was created. Bioethanol with an admixture rate of 20 to 25% is part of the normal fuel mix. Almost all automobiles sold are »flexible fuel vehicles« that can operate with any mixture of gasoline and ethanol. Even before Brazil, the USA is now the largest producer of bioethanol and the world market leader in the production of bioethanol from corn.

In Europe, 5% ethanol has been added to gasoline since the 1980s. For several years, E10 (10% ethanol) has been available in various countries. The EU has come out in favor of supporting biofuels. In the member states, this is promoted by tax incentives or a mandatory blending policy. The minimum goal of the EU is to meet 10% of energy demand in the transport sector by renewable energies by the year 2020.

BIOETHANOL IN HISTORY

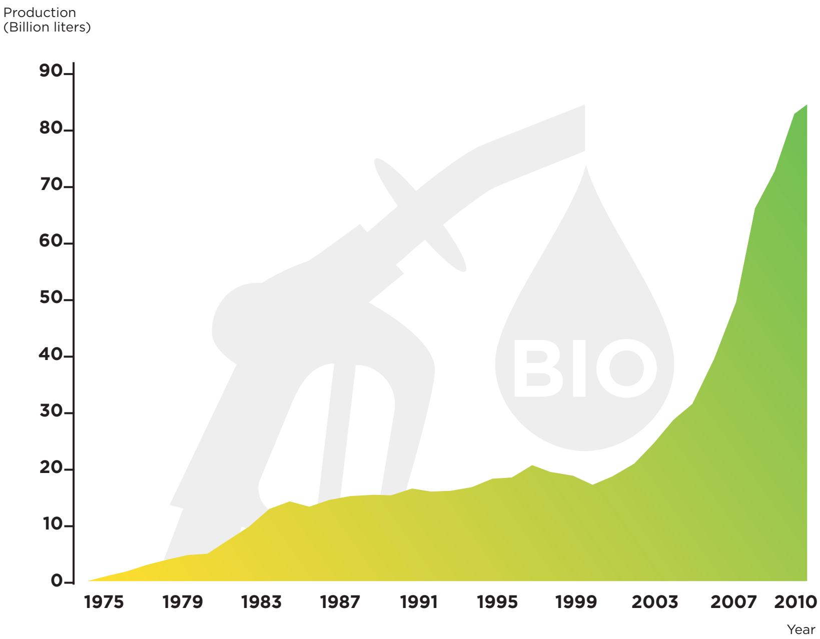


The global market for bioethanol is growing rapidly; the sales volume doubled between 2003 and 2007 alone. The further development of the bioethanol market is promoted by the regulatory framework conditions in the USA and European Union. In the USA, 15% of consumed fuel will have to be replaced by biofuels by 2022. The EU mandates that 10% of energy consumed in the transport sectors will have to originate from renewable sources by 2020. The anticipated price increases for crude oil based fuels are also generating further impulses in favor of bioethanol.

The demand for biochemicals is also increasing in the chemical industry due to dwindling resources of fossil raw materials. For example, Clariant technologies can be used to upgrade cellulosic ethanol into valuable platform chemicals. In addition, the technology platform can also enable the manufacture of other chemicals from the cellulosic sugars. This opens up new opportunities to the chemical industry for a seamless alternative value chain based on renewable resources. A quick look at current market forecasts shows the scope of this potential: Deutsche Bank research experts forecast an annual sales hike of 10% for »white biotechnology« by 2015.

The sunliquid® demonstration plant in Straubing in Bavaria is Germany's first and so far largest of this kind. It is designed to establish the innovative process on the industrial scale and offers licensees from around the world the opportunity to acquaint themselves with the process and later operate industrial plants with an annual output of 50,000 to 150,000 tons of bioethanol annually with this technology.

SURVEY OF GLOBAL BIOETHANOL PRODUCTION FROM 1975 TO 2010



Source: Biofuels and World Agricultural Markets: Outlook for 2020 and 2050; Guyomard Hervé et al. in: Economic Effects of Biofuel Production, book edited by M. A. dos Santos Bernardes, ISBN 978-953-307-178-7, 2011.

THE STRENGTHS OF THE SUNLIQUID® PROCESS

- 95% fewer climate gas emissions compared to fossil gasoline
- minimal costs for the required biocatalysts, as they are generated directly in the process itself
- high sugar yields due to raw material and process specific enzymes
- 50% higher ethanol yield due to simultaneous C_5 and C_6 fermentation
- 50% lower energy consumption due to adsorbers, ethanol remains adhering to the surface and is then separated off
- flexible use of different raw materials and plant designs
- no competition with the food industry

BIOETHANOL – THE GLOBALLY DOMINANT BIOFUEL

19.9 Billion liters biodiesel*

85.8 Billion liters bioethanol

Source: F. O. Licht, 2010
*Forecast

ADSORBER (from the Latin *adsorbere* »to draw in«): Substance on whose surface other substances – usually gases or liquids – remain adhering and accumulate there due to a physical process.

ARABINOSE: Naturally occurring monosaccharide consisting of five carbon atoms, hydrogen and oxygen (empirical formula $C_5H_{10}O_5$). Is also known as pectinose, rubber sugar or aloin sugar.

BAGASSE: Fibrous residues produced during sugar manufacture from sugar cane or sorghum millet. This by-product is obtained when the sugar juice is pressed out of the plant.

BIOCATALYST: See enzyme.

BIOETHANOL: Ethanol produced exclusively from biomass or the biodegradable part of residues and intended for use as biofuel or a chemical.

BIOMASS: Mixture of substances bound in animate beings (plants, animals, microorganisms) and/or produced by them.

CELLULOSE: Polysaccharide consisting of several hundred to ten thousand glucose molecules. As a main constituent of plant cell walls, cellulose is the most common organic compound in existence and, for example, is an important raw material for paper manufacture.

ENZYME (artificial word derived from the Greek *en* »in« and *zýme* »sourdough, yeast«): Substance that can initiate, accelerate or control biochemical reactions. Enzymes (also known as biocatalysts) have an important function in the metabolism of organisms.

ETHANOL: Monovalent alcohol (empirical formula C_2H_6O). Constituent of alcoholic beverages such as wine, beer and hard liquor; also used as solvent and disinfectant, starting material for chemicals and as a fuel.

FERMENTATION (from the Latin *fermentum*): Conversion of organic substances by enzymes, but also bacterial, fungal or other biological cell cultures. The best known example is the conversion of sugar to alcohol.

GLUCOSE (from the Greek *glykýs* »sweet«): Monosaccharide with the empirical formula $C_6H_{12}O_6$ from the group of carbohydrates. Is also known as dextrose and is produced mainly by plants by photosynthesis from sunlight, carbon dioxide and water.

HEMICELLULOSE: Collective term for mixtures of polysaccharides present in plant biomass. Hemicellulose is a constituent of plant cell walls and serves as a structural and supporting substance.

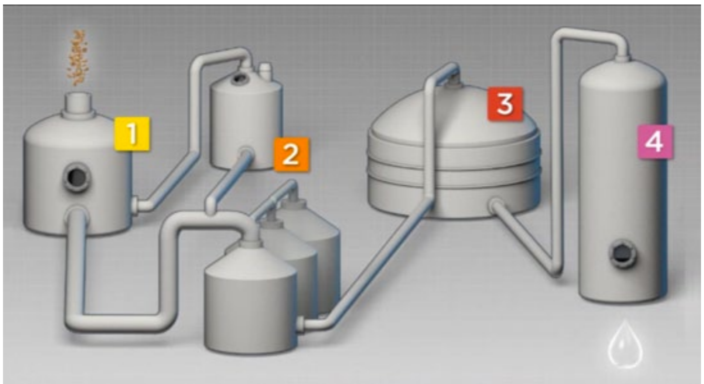
LIGNIN (from the Latin *lignum* »wood«): Substance made of extensively branched macromolecules composed of different building blocks. They are incorporated in the plant cell wall where they induce lignification of the cells.

LIGNOCELLULOSE: Close combination of cellulose, hemicellulose and lignin that forms the cell wall of lignified plants. Lignocellulose is difficult to access for enzymes because of its dense structure and protects the plant against pests like fungi and bacteria.

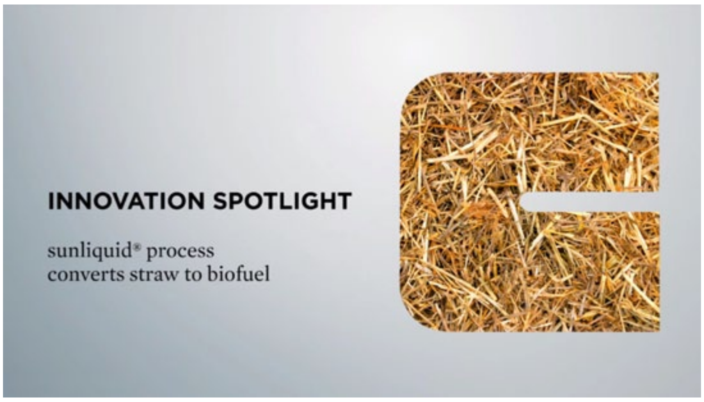
XYLOSE: Type of sugar with five carbon atoms (empirical formula: $C_5H_{10}O_5$), also known as wood sugar. Used to produce the sugar substitute xylite. Xylose is not degraded by the human body and is eliminated intact.

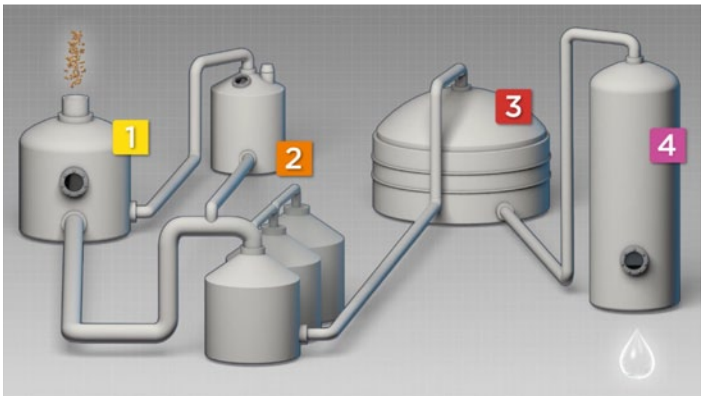
SUNLIQUID® DEMONSTRATION PLANT
in Straubing

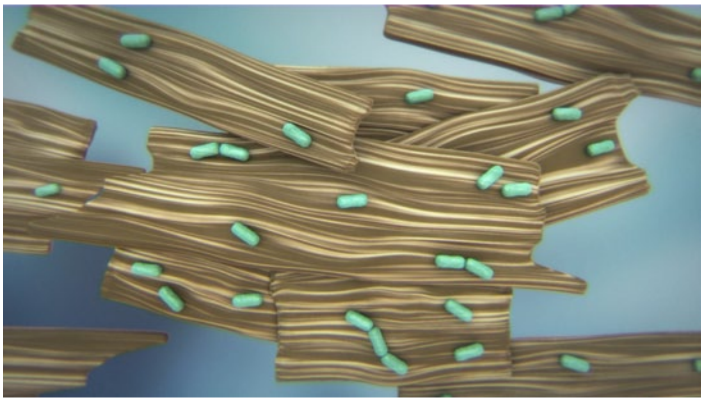
DOWNLOADS FROM IMAGES SECTION

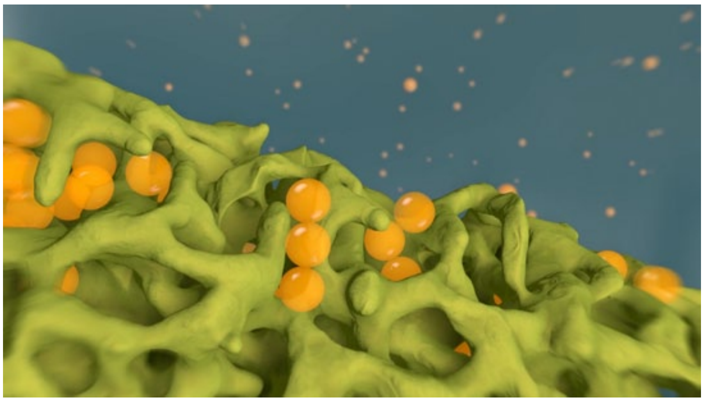


DOWNLOAD ANIMATION

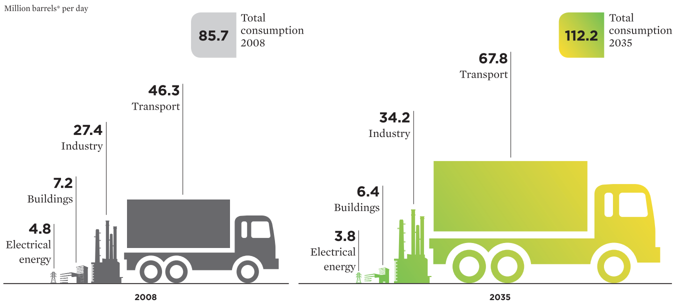








WORLD LIQUID FUEL CONSUMPTION 2008 AND 2035



Source: http://www.eia.gov/forecasts/ieo/liquid_fuels.cfm

MAIN LIGNOCELLULOSIC FEEDSTOCKS IN DIFFERENT REGIONS OF THE WORLD

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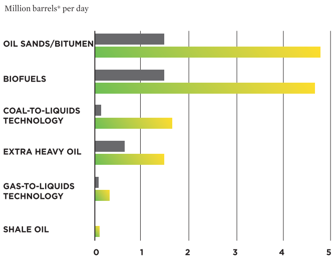

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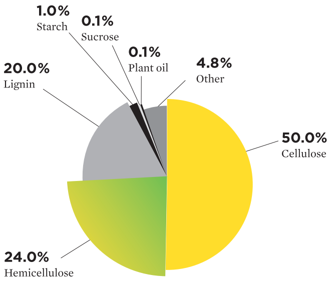

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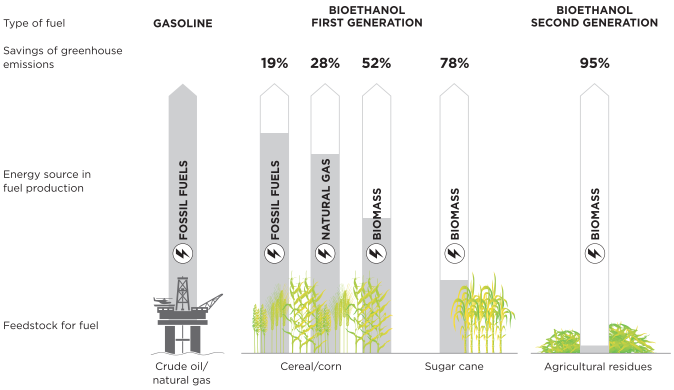

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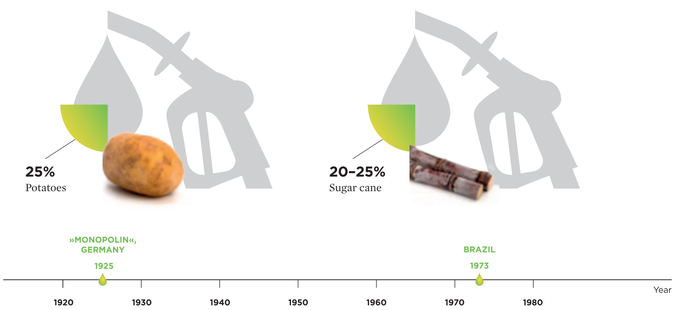
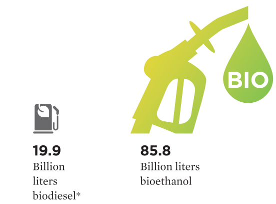
BIOETHANOL IN HISTORY



BIOETHANOL – THE GLOBALLY DOMINANT BIOFUEL



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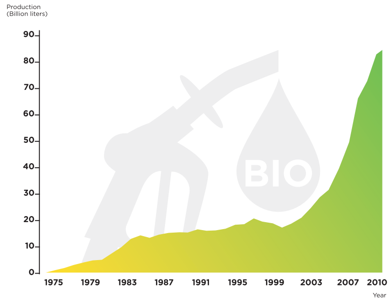

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