INNOVATIONSKLUSTER FÖRNYBARA DRIVMEDEL

f3 FACTS

Bioethanol

Bioethanol is the most used biofuel for transportation. It can be produced from many different raw materials and through different production processes. Today, mainly technologically conventional methods are used, such as fermentation from sugar- and starch-based feedstock. Production of so called advanced bioethanol utilizes methods developed to make use of either lignocellulosic types of biomasses, e.g. residues from the forestry and agriculture sector and waste material, or of syngas of various origins.

Properties

Chemical formula: C_2H_5OH
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

Ethanol is a volatile, colorless, flammable liquid that burns with an almost invisible flame and has a characteristic odor. As a versatile solvent, ethanol is miscible with many organic components as well as water. It can also be used to produce ETBE, an oxygen agent in gasoline.

Primary area of use

Bioethanol and synthetic ethanol are chemically the same molecule, and therefore identical from a usage perspective. Low blending of ethanol into vehicle fuel was introduced as an oxygen agent to reduce CO_2 emissions. The usage is spread and extensive around the world, mainly as low blending in gasoline in different proportions. Today, blends up to E25 (meaning that 25% of the volume is ethanol) are marketed and used in conventional cars.

In the U.S., the average share of ethanol in gasoline during summer 2022 was around 10%. (U.S. Energy Information Administration 2025). In Brazil, all automotive gasoline sold at retail since 2015 contains, by mandate, 27% of anhydrous ethanol (IEA Bioenergy 2021)

The European Fuels Quality Directive allows up to 10% of ethanol in gasoline. E10 is available in 19 EU countries and the U.K. Still, and despite the nearly full acceptability of E10 by the EU car fleet, the E10 market share in many European countries is lagging. In 2024, the market share was 26% and 58% in Germany and France respectively (Epure 2025). E20 is under normalization in CEN, scheduled for 2026, but will also require a Fuels Quality Directive update, under European Commission responsibility, before marketing can take place. (ETIP Bioenergy 2024)

In Sweden, E10 is the most common gasoline quality on the market, often sold as “bensin 95 E10”. The introduction of E10 took place when the national reduction obligation scheme, a regulation for mandatory blending of biofuel into gasoline and diesel, was increased to 6% in 2021. About 94% of all gasoline cars on the roads in Sweden accept E10. The remaining cars must fill up with E5 which is not available in all gasoline stations in Sweden. (Drivkraft Sverige 2025)

Ethanol is also used in flexible-fuel vehicles (FFVs) that can run on ethanol/gasoline mixtures ranging from pure gasoline to E85 (85% ethanol mixed with 15% gasoline) or even E100 (100% hydrous ethanol)[1] (Unica n.d., Bosch 2026). Brazil is a frontrunner leading the FFV market development. In 2022, 83% of new car sales were FFV (Advanced Biofuels USA 2023). In the U.S. 7% of new car registered in 2023 were FFV (US Department of Energy 2025a). In Europe, only 0,9% of new registrations were bioethanol- or FFV in 2024[2].

For heavy vehicles, a slightly modified diesel engine with compression ignition can use ED95, an ethanol fuel with ca 95 % hydrous ethanol and ca 5% ignition improver. In Sweden, it is only available at some fuel stations and bus hubs. (Drivkraft Sverige 2025)

The suitability and flexibility of ethanol for transportation is good. The thermal efficiency of ethanol when used in gasoline engines (Otto-engines) is higher than for pure gasoline, especially if the engine is designed for high-octane fuel. Furthermore, ethanol provides an inherent protection against ice formation which makes the

[1] Ethanol is either anhydrous (“all” water from the production process has been removed) or hydrous (roughly 7 vol-% remain in the ethanol). E85 is 85% anhydrous ethanol and 15% gasoline. E100 is 100% hydrous ethanol (i.e., ca 7% water).
[2] Eurostat (2026), data code: **road_eqr_carpda**. Percentage calculated from sum of “bioethanol” and “bi-fuel” sales.

addition of carburator antifreezing agent unnecessary. However, the energy content per liter is 34% lower in ethanol than in gasoline. When ethanol is used as E5, these effects cancel out and the ethanol substitutes the same volume of gasoline. For higher ethanol blends, the fuel volume increases, leading to shorter driving range with the same tank size. In the diesel engine, ED95 has the same thermal efficiency as diesel, which means 20–30% higher than an Otto-engine.

There is a growing interest in ethanol as feedstock to produce sustainable aviation fuel using so called "alcohol-to-jet" technology. A summary of production plants under development can be found at the bottom of this fact sheet).

Feedstock and production

Ethanol can be produced from almost all types of biomass. Currently, almost all commercial plants use sugar and starch rich biomass like sugarcane, sugar beet, corn, wheat, and other grains. The process used for production of ethanol is fermentation of sugars. For grains, an enzyme hydrolysis of the starch is needed. Production using these feedstocks is well-established, both from a technological and a commercial perspective.

Several alternative processes for ethanol production are under development to widen the feedstock base from food and feed to e.g. (ligno)-cellulose and waste. Ethanol produced from non-food or feed feedstock is generally referred to as "advanced". Alternative feedstocks are more challenging to use. Cellulose biomass needs a pre-treatment step to open up the structure before the formed sugars can be enzymatically hydrolyzed and fermented, and waste-based processes often face challenges related to, e.g., logistics and variations in feedstock quality.

In principle, two alternative processes for ethanol production are under development:

- Use of (ligno)-cellulosic biomass in conventional fermentation processes. This requires pre-treatment before the fermentation process.
- Fermentation or catalytical reformation of syngas to ethanol. The syngas can be either a waste-stream from industrial processes (e.g., steel production) or produced specifically for ethanol production via biomass gasification

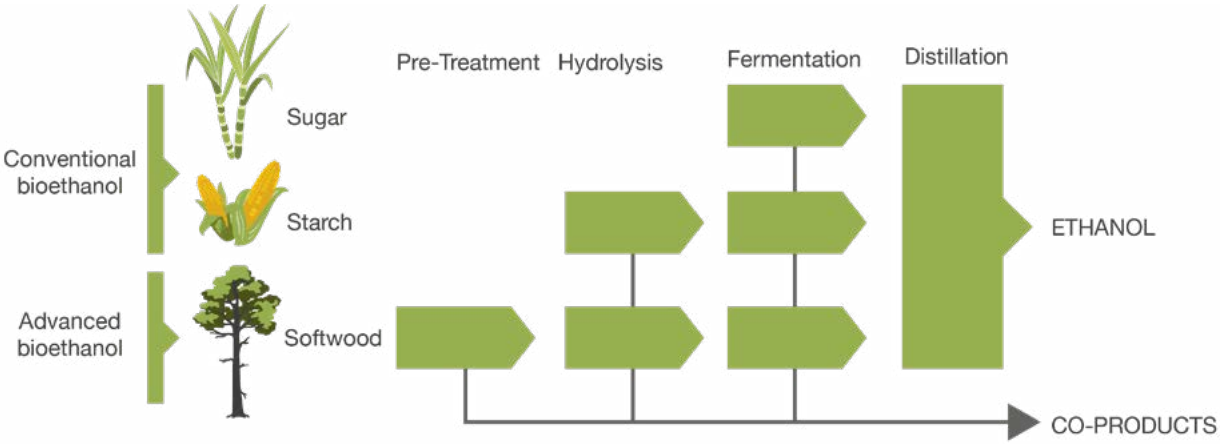

Figure: Overview of ethanol production processes.

Current production volumes

Ethanol is the most used biofuel today. In 2025, 121 billion liters were produced globally out of which the U.S. and Brazil together accounted for 80%. Ethanol represents more than 60% of the global production of liquid biofuels. (World Bioenergy Association 2025).

The production of bioethanol increased rapidly during 2007-2010. Later, it has grown at a slower pace. Production fell worldwide in 2020 because of the COVID-19 pandemic. (US Department of Energy 2025b) and didn't exceed pre-pandemic levels until 2023. (World Bioenergy Association 2025)

Distribution system

The distribution of E5 to E25 and E85 is generally handled by gasoline suppliers in each country by blending with ethanol at the oil depot. The risk handling and classification are almost the same as for gasoline. ED95 is mainly purchased by fleet owners and the distribution is tailored for each customer.

Tankers are used for long-distance (e.g. transatlantic) transportation of ethanol. Dewatered ethanol for blending in gasoline is hygroscopic (meaning it takes up water) and during storage and transportation nitrogen is used to replace air and minimize breathing in the tanks, caused by temperature differences.

Projects for advanced ethanol production

Below, existing and planned plants for advanced ethanol production, are described. The plants were identified using the IEA Bioenergy Task 39 database (IEA Bioenergy 2026).

Pre-treatment followed by conventional fermentation

Technology to produce ethanol from cellulosic biomass has been developed and verified by several companies, for example Sekab, New Energy Blue/Inbicon, Blue Biofuels, Clariant, and Abengoa, in pilot scale and small demo scale up to more than 80 million liters/year. (IEA Bioenergy 2020)

The global installed capacity for advanced ethanol production via conventional fermentation with pre-treatment is about 320 ktpa or roughly 250 million liters. This is ca 0,2% of the global ethanol production in 2023 (see above). (IEA Bioenergy 2026).

Many large-scale production plants were developed in the 2010's but suffered financial and technological setbacks. After years of low capacity utilization, outages and ownership changes, several of these flagship projects have been shut down.

One pioneering plant that is still in operation is a 25 ktpa plant in Crescentino, Italy. Inaugurated in 2013 under the ownership of Beta Renewables, it was the first commercial scale cellulose-to-ethanol plant in Europe with a design capacity of 60 ktpa. After Beta Renewables' bankruptcy, the assets were acquired by Versalis, an Eni subsidiary, in 2018. Production was restarted in 2021 at the current capacity of 25 ktpa of advanced, RED-compliant ethanol. (Bioenergy International 2020, Eni 2022, Versalis 2025).

Other companies with long experience in cellulosic ethanol include GranBio and Raizen, both of which operate in Brazil. Since 2014, GranBio operates a 65 ktpa plant producing ethanol from sugarcane bagasse and straw (IEA Bioenergy 2026).

In May 2024, Raizen announced the inauguration of a new cellulosic ethanol plant at the Bonfirm Bioenergy Park in Guariba, Sao Paulo, Brazil. The facility, with a capacity of 82 million liters ethanol per year (65 ktpa), converts sugarcane bagasse feedstock into (advanced) cellulosic ethanol. The facility is the second cellulosic ethanol plant developed by Raizen. (Ethanol Producer Magazine 2024) The company opened its first cellulosic ethanol plant in 2015 at the Costa Pinto Bioenergy Park in Piracicaba, São Paulo, Brazil, which in April 2025 transitioned to a testing and R&D facility. (Ethanol Producer Magazine 2025).

According to the IEA Bioenergy database, roughly 450 ktpa of capacity is planned or under construction. Out of this, over 300 ktpa is linked to five plants being developed by Raizen in Brazil.

Fermentation or catalytic reformation of syngas

Ethanol can be produced from syngas ($CO+H_2$) either catalytically in a chemical reactor or by fermentation in bioreactors. Syngas is available in many industrial off-gases, e.g., from primary steel production and petroleum refining, but may also be produced specifically for ethanol production by gasification of virtually any solid biomass.

Six syngas-based ethanol plants of commercial scale are in operation, and the longest serving plant has been operational since 2018. All use LanzaTech's technology for syngas fermentation and have a combined capacity of ca 340 ktpa. The plants use off-gases from steel mills, ferroalloy plants and refineries as feedstock. (LanzaTech 2026).

No commercial scale gasification-based ethanol plants are in operation. However, the Canadian company Enerkem has developed a process to produce ethanol and other chemicals (mainly methanol) from municipal solid waste. The waste feedstock is first gasified and then sent to a catalytic reactor that produces the targeted chemical(s). Enerkem has operated pilot- and demo plants since 2003 and 2009, respectively, but no commercial scale plant is currently in operation. Enerkem commissioned a commercial scale (30 ktpa) ethanol plant in Edmonton, Canada, in 2014 but the plant was shut down in 2024. According to Enerkem's press release, the decision was made after the plant had achieved its objective of completing the commercial scale-up of the company's technology, and "factoring in the current market and domestic regulatory conditions". (Enerkem 2024, IEA Bioenergy 2026).

Alcohol-to-jet projects

Recent years have seen a rising interest in "alcohol-to-jet" processes for sustainable aviation fuel production. The process is ASTM-certified and uses alcohol feedstock (predominantly butanol or ethanol) to produce aviation fuel through several chemical reactions (dehydration, hydrogenation, oligomerization, and hydrotreatment). (Alternative Fuels Data Center n.d.) One commercial scale plant (27 ktpa) is operational in the United States and uses LanzaTech's LanzaJet technology. Roughly 1 000 ktpa of capacity is under development, most of which is based on the LanzaJet technology. (IEA Bioenergy 2026)

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f3 Innovation Cluster for Renewable Transport Fuels is a network organisation with a long history of stakeholder collaboration in system-related research on renewable fuels.

Industry, universities, institutes, and authorities participate in f3. Together, the members create new collaborations, increase knowledge, and identify barriers and opportunities and possible solutions for actual and rapid transition to renewable fuels in the transport sector.

The Innovation Cluster is financed by its member organizations together with the Swedish Energy Agency and is hosted by Chalmers Industriteknik.

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