Bioethanol

Fueling Sustainable Transportation

Availability of biomass materials on a sustainable basis exceeds 200 million tons annually—enough for 20 billion gallons of ethanol each year.

What is Bioethanol?

- A domestically produced liquid fuel made from renewable plant resources known as biomass
- A renewable transportation fuel whose production contributes only small amounts of fossil-derived carbon dioxide (CO_2) to the Earth's atmosphere
- A high-octane fuel that can contribute substantially to the U.S. automotive fuel supply
- A fuel that can be used in a blend with gasoline or neat (95% ethanol with a denaturant), with excellent efficiency and performance
- A clean-burning fuel that reduces urban air pollution.

The Resource

Today, most U.S. ethanol production is based in the grain-growing states of the Midwest, where over 500 million bushels of corn and other starch crops are used as feedstocks to produce approximately 1.4 billion gallons of ethanol annually. At about 1.1% of U.S. gasoline consumption, ethanol represents a small percentage of our total transportation fuel supply. But demand is growing for this alternative to petroleum, and for ethanol production to keep up with increasing demand, feedstock supplies for the fuel must also keep pace. To meet this need, the U.S. Department of Energy (DOE) is, in conjunction with private industry, developing ways to use abundant, low-cost cellulosic biomass. Plentiful, domestic, cellulosic biomass feedstocks such as herbaceous and woody plants, agricultural and forestry residues, and a large portion of many municipal solid waste and industrial waste streams, can be converted to ethanol. Availability of these materials on a sustainable basis exceeds 200 million tons annually—enough for 20 billion gallons of ethanol each year. Because corn cobs, leaves, and stalks are made of cellulosic material, these research efforts will also allow the corn industry to use parts of the corn plant that are now waste, and expand beyond the limits of starch-derived ethanol.

Agricultural by-products such as corn stover can now be used as feedstock for making bioethanol.

Making fuels from biomass involves a variety of thermal, chemical, and biological processes.

The Process

Cellulosic biomass is a complex mixture of plant cell wall carbohydrate polymers known as cellulose and hemicellulose, plus lignin and a smaller amount of other compounds known as extractives. To produce ethanol from biomass feedstocks, two key processes must occur. First, the hemicellulose and cellulose portions of the biomass must be broken down into simple sugars through a process called saccharification. Second, the sugars must be fermented to make ethyl alcohol or ethanol. A variety of thermal, chemical, and biological processes can be used to produce ethanol from biomass. Several U.S. research organizations and companies are exploring combinations of these processes to develop the most efficient and economical route for the commercial production of ethanol.

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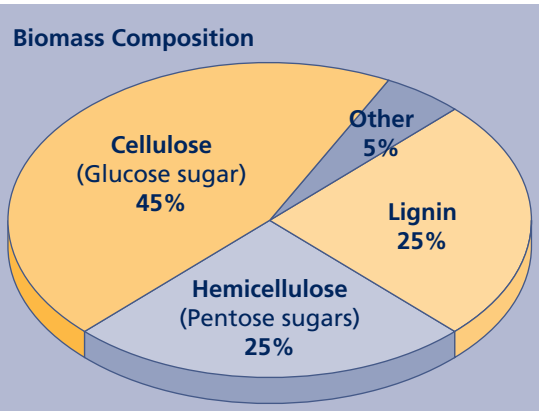


Utilization

The Clean Air Act Amendments of 1990 mandated the sale of oxygenated fuels in areas of the country with unhealthy levels of carbon monoxide. Since that time there has been strong demand for ethanol as an oxygenate blended with gasoline. Several ethanol blends have been tested, and some are being distributed by service stations throughout the United States. E10 (10% ethanol, 90% gasoline) is the most commonly distributed, with nearly 1 billion gallons being distributed in 2000. E20 (20% ethanol, 80% gasoline) is used in some other countries and is being considered for promotion in the United States. E85 and E95 (85% and 95% ethanol, respectively) have been successfully tested in North America in government fleet vehicles, flexible-fuel vehicles (FFVs), and urban transit buses. There are 52 E85 refueling sites in the United States that will distribute approximately 3.3 million gallons of E85 during 2000.

During the past several years, the number of FFVs (which run on gasoline, E85, or any blend of the two) available in the United States has increased dramatically. In model years 1998 and 1999, Ford Motor Company and DaimlerChrysler introduced FFVs that include the flexible fuel system as standard equipment. Until now, prospective buyers had to specifically request an FFV and pay incremental costs for the vehicles. Nearly 500,000 FFVs are projected to be on the road in 2000.

Environmental Benefits

Our dependence on petroleum-derived fuels is detrimental to our environment. Fueling our automobiles with ethanol offers an alternative to fossil fuels with far fewer impacts.

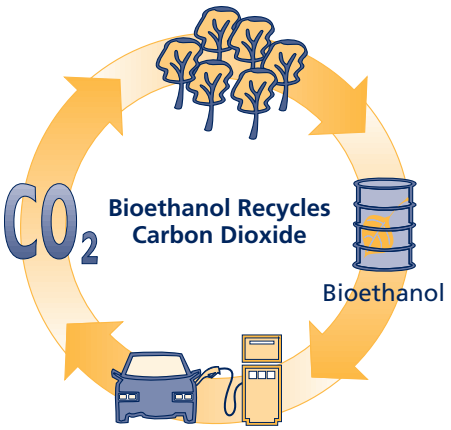
The transportation sector is responsible for one-third of our country's carbon dioxide (CO_2) emissions, the buildup of which may contribute to global warming. Producing and using ethanol can help reduce CO_2 buildup significantly. By displacing the use of fossil fuels, the emissions resulting from fossil fuels use are avoided, and the CO_2 content of fossil fuels is allowed to remain in storage. Further reductions occur because the plants and trees that serve as feedstocks for biofuels require CO_2 to grow, and they absorb what they need from the atmosphere.

E85 is used by many government and business vehicle fleets with great success.

Ford and DaimlerChrysler have recently introduced flexible-fuel vehicles to the public.

Ethanol is also an effective tool for reducing air toxics that come from the transportation sector. These are pollutants that the U.S. Environmental Protection Agency classifies as known or probable human carcinogens. Air toxics are weighted according to the relative level of risk for each of the toxic compounds emitted. Based on this potency weighting system, ethanol use results in an overall lower weighted risk factor for air toxics including benzene, formaldehyde, acetaldehyde, and 1,3-butadiene.

Ethanol can also protect our land and water against the effects of large fuel spills or leaks that occasionally occur during fuel storage and transport. Because it is low in toxicity, water soluble, and easily biodegradable, harm to the environment in case of a spill is minimal.



The Program

DOE's Office of Fuels Development sponsors and supports the Biofuels Program at the National Renewable Energy Laboratory (NREL). A major part of this program is devoted to the conversion of biomass to ethanol, or bioethanol. Through in-house research, subcontracts and cooperative research and development agreements with industry partners, universities, and other national laboratories, NREL leads DOE's efforts for the development of new technology for bioethanol production.

These partnerships are formed to develop and support the commercialization of technologies to create a new bioethanol industry in the United States by reducing bioethanol manufacturing costs and supporting the commercialization of this emerging technology.

Artist's rendition of proposed rice straw-to-ethanol plant near Sacramento, California.

Through nearly 20 years of R&D, significant strides have already been made in the economical conversion of biomass to ethanol. During the past decade, the Biofuels Program has succeeded in reducing the projected cost of ethanol to the range of $1.00/gallon when it is produced from low-value biomass.

To support commercial application of biomass-to-ethanol conversion technology, DOE's Alternative Fuels User Facility (operated by NREL's Biotechnology Center for Fuels and Chemicals) contains R&D laboratories and a biofuels pilot plant. This plant can process 1 ton of dry feedstock per day. Qualified partners from private industry can use the facility to test processes and feedstocks to obtain the data they require to design, build, and operate their ethanol plants.

Several major goals direct the efforts of the Biofuels Program:

- Commercial demonstration-scale production of ethanol using a low-cost niche feedstock by the end of the year 2001.
- Commercial demonstration-scale production of ethanol using corn stover and/or a dedicated energy crop as its feedstock supply by the end of the year 2005.
- Large-scale commercial production of ethanol that will be cost-competitive with petroleum in the transportation fuel market in 2010 and beyond.

Challenges

Even with advances made in biomass conversion technology, ethanol struggles to compete economically with cheap sources of crude oil. The current federal excise tax incentive of 54 cents per gallon allows ethanol to compete in the marketplace by providing a reduced tax payment to gasoline blenders that use ethanol. But for ethanol's share of the transportation fuel market to grow beyond the blend market, continued R&D is required to make ethanol competitive with gasoline. Targets have been established and the pathway is clear for an aggressive R&D program that is needed to reduce the cost of producing fuel ethanol to competitive values.

Another challenge facing wider use of ethanol is its energy content—only about two-thirds the energy of an equal volume of gasoline. However, this deficiency can be largely overcome by using high-compression ratio engines that take advantage of the high-octane properties of ethanol. At blend levels of 10%, this has little impact on consumers. For higher concentrations of ethanol, as would be used in dedicated ethanol vehicles, continued R&D directed toward improving ethanol vehicle efficiency is needed.

Overall, the environmental benefits, domestic producibility, and economic boost that a biomass-based ethanol industry could provide our country make ethanol a very promising transportation fuel alternative.

For more information, visit the National Biofuels Program's web site at www.ott.doe.gov/biofuels

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R&D Facilities for Reducing Cost of Producing Bioethanol

For ethanol's share of the transportation fuel market to grow beyond the blend market, continued R&D is required to meet process performance targets to make ethanol competitive with gasoline. Toward reaching these performance targets, DOE's Office of Fuels Development has assembled a collection of state-of-the-art facilities dedicated to R&D of biomass conversion technologies. Through a variety of contractual arrangements, these facilities are available for industry and research institutions to develop, improve, test, and demonstrate their technologies.

Located at the National Renewable Energy Laboratory, bioethanol research facilities include a bioethanol pilot plant. The pilot plant offers five major components: a 1-ton-per-day process development unit (PDU), a bench-scale pretreatment laboratory, a 4-liter steam gun, a pilot countercurrent pretreatment system, and a pilot-scale continuous chromatography system. The PDU includes all operations to convert biomass into ethanol, including feedstock handling and size reduction, enzyme production, pretreatment, hydrolysis, seed growth, fermentation, distillation, and solid-liquid separation.

NREL's bioethanol process development unit