NREL Advances in Technology at the National Renewable Energy Laboratory

Technology Brief

Joining Forces for Biofuels

NREL and Amoco to Demonstrate Technology to Turn Landfill Wastes into Ethanol for Clean-Burning Transportation Fuel

Each year, Americans send about 180 million tonnes (200 million tons) of municipal solid waste (MSW) to landfills. While many see this as a disturbingly large amount of trash, the Amoco Corporation and the National Renewal Energy Laboratory (NREL) see it as a great opportunity. Amoco and NREL have teamed up to establish an industrial process that could transform more than two-thirds of that waste from a landfill burden into a valuable transportation fuel resource and tool in fighting air pollution. These two organizations are collaborating in a 6-year cooperative research and development agreement (CRADA) to demonstrate technology developed by NREL—a U.S. Department of Energy (DOE) national laboratory—for making ethanol from biomass such as the paper and yard trimmings in MSW.

Ethanol—an Excellent Additive and Alternative Fuel

Ethanol made from corn is already used as an additive in about 9% of the gasoline sold in the United States. Ethanol is an oxygenate that boosts octane and reduces carbon monoxide and hydrocarbon emissions. The Clean Air Act Amendments of 1990 require the use of oxygenated fuel additives, such as ethanol, in many cities designated as having air pollution problems. Also, the U.S. Environmental Protection Agency recently directed—via its renewable oxygenate standard—that 30% of oxygenated fuel additives must be made from renewable sources. Therefore, continued environmental pressure will further increase the demand for ethanol and ethyl tertiary butyl ether (ETBE) made from ethanol.

Ethanol is also one of the best choices for a pure or "neat" alternative fuel. It requires a few vehicle modifications, but it works well and greatly reduces polluting emissions. About 40% of the cars in Brazil use neat ethanol made from sugarcane. A number of public fleet vehicles in the United States are currently being tested with blends of 5% or 15% gasoline added to improve cold-starting of the engines. Domestic production of fuel ethanol will also help create jobs, reduce dependence on foreign oil, and improve our balance of trade.

Special Processes and Microorganisms to Meet the Challenge of Biomass

Making ethanol from sugarcane or corn starch is relatively easy. Common enzymes that break down starch into sugars, as well as yeasts

Photo courtesy of Amoco

Warren Gretz, NREL

NREL's new Alternative Fuels Users Facility (at right) provides the research and pilot plant facilities for cooperative research and development work with the Amoco Corporation to turn landfill wastes, such as paper and yard trimmings, into a valuable transportation fuel and air quality tool—ethanol from biomass.

NREL's Biomass-to-Ethanol Technology

NREL's technology for making ethanol from biomass such as municipal solid waste (MSW) includes several processes. The first step separates out noncellulosic material from the MSW and mechanically mills the cellulosic material to reduce its size and increase available surface area for pretreatment. Pretreatment is one of the most crucial steps for the project as it must be specifically matched to the MSW feedstock. In pretreatment, chemicals break down the hemicellulose into sugars, dissolve some of the lignin that surrounds the cellulose, and open up the structure of the cellulosic material. The hemicellulose sugars go into solution, allowing separation from the still-solid cellulose.

Next, the cellulose is hydrolyzed to glucose sugars by cellulase enzymes, and the resulting sugars are simultaneously fermented by yeasts in a continuous process to produce ethanol. The operating conditions of each of a series of fermenters can be independently adjusted to maximize the productivity of each stage. Xylose and the other sugars derived from hemicellulose during pretreatment are fermented separately by special microorganisms identified by researchers.

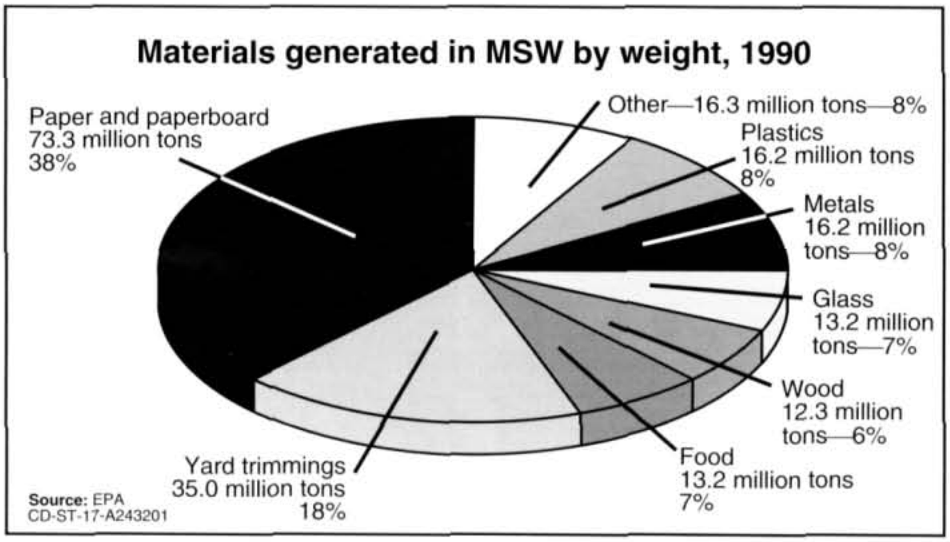
After fermentation, the "beer" containing the ethanol is removed and distilled to produce pure ethanol. Nutrients, microorganisms, and enzyme broth can be recovered and cycled back into the process. The residue (mainly lignin) is burned as boiler fuel to drive the process. During the pilot-plant phase, alternatives for these steps will be tested for their impact on process efficiency and economics.

that ferment the sugar into ethanol, have produced alcoholic beverages for man since ancient times. Most of the carbohydrates in plant materials that end up in MSW landfills, however, are more difficult to ferment. These carbohydrates are cellulose and hemicellulose—the fibrous material that gives plants their strength and structure. The links that form the chains of sugars in cellulose and hemicellulose are not easily broken, and they pose a challenge for the biomass-to-ethanol conversion process.

The Amoco CRADA puts NREL's new technology to work in a comprehensive industrial process.

Researchers at NREL, however, have developed a sophisticated set of biotechnological tools to break, or hydrolyze, the interconnecting bonds in cellulose and hemicellulose, thus making it possible to produce alcohol from biomass. They have developed pretreatment processes that make the biomass more accessible to microorganisms. They have selected fungi and bacteria that produce large quantities of cellulase enzymes that convert cellulose to sugars. They have also developed specialized microorganisms that ferment these sugars to ethanol. And they have combined hydrolysis and fermentation into an effective single process (simultaneous saccharification and fermentation, or SSF). Although hemicellulose is easier to break down into sugars than cellulose is, the primary sugar obtained—xylose—is not fermentable by common yeasts. In a major breakthrough, NREL scientists have metabolically engineered a glucose-fermenting bacterium to also ferment xylose, making cofermentation of glucose and xylose possible. Laboratory work in all these areas focuses on increasing efficiency, optimizing the continuous SSF process, and recycling the biocatalyst (enzymes and microorganisms) (see sidebar at left).

In parallel with their experimental work, NREL researchers have enhanced their understanding of the biomass-to-ethanol conversion process by mathematically modeling the kinetics of SSF. Linked to a techno-economic process simulation model, the SSF model is helping NREL determine the impact of various factors on the cost of ethanol production. Such information is invaluable for scale-up and commercialization, and the NREL models will play a key role for the Amoco CRADA.



More than two-thirds of municipal solid waste—paper and paperboard, yard trimmings, food waste, and wood—can be converted to ethanol using the technology NREL and Amoco are developing.

CRADA Will Prepare Technology for Commercial Production

The four-phase NREL-Amoco CRADA provides the opportunity to put NREL's new technology to work in a comprehensive industrial process to demonstrate it and analyze its economics. During the first phase of the project, Amoco scientists and engineers reviewed the conversion technologies developed by NREL; then they joined with NREL researchers to examine potential MSW and other feedstocks and to conduct preliminary engineering and economic analyses. In the second phase, researchers performed additional bench-scale work to answer key questions and fill in data gaps to refine their analyses. To support the third phase of the CRADA, NREL has built a new process development unit (PDU)—a pilot plant that will be capable of handling 900 kg (1 ton) per day of feedstock. Continuous operation at the pilot-plant scale will allow for more definitive engineering and economic analyses and continued improvements to the technology.

In the final phase, Amoco will set up a large-scale facility to demonstrate the biomass conversion process at an engineering demonstration level. The Amoco facility will convert 36,000 to 90,000 kg (40 to 100 dry tons) of feedstock per day. At the end of this demonstration run, NREL and Amoco will have complete data to determine commercial viability, and Amoco will be able to move to industrial operation. Such an industrial facility would probably be sized to process about 2 million kg (1800 tons) of feedstock per day to produce about 200 million liters (53 million gallons) of ethanol per year. Total DOE expenditures for NREL operations during the life of the project will be about $4 million, with most of that to be spent in the second and third phases; Amoco expenditures of up to $25 million will occur largely in the final phase.

New NREL Facility Will Aid Project

NREL's new Alternative Fuels Users Facility (AFUF) houses the pilot plant to be used for Phase 3 of the NREL-Amoco CRADA project—a 743-square-meter (8000-square-foot) process development unit (PDU). The PDU's feedstock capacity of 900 kg (1 dry ton) per day will improve assessment of the operability of the biomass-to-ethanol process and allow testing of commercially available equipment. The PDU employs four 9000-liter fermentation tanks. a continuous-process pretreatment reactor, a 12-meter distillation column, inoculation tanks, centrifuges, and utilities. In 1995, three additional fermenters will increase the total capacity to 63,000 liters. This will allow the simultaneous study of cofermentation as well as separate glucose and xylose fermentation.

The AFUF also contains two integrated process development laboratories in which researchers can test operations and processes linked as they would be in actual production. The study of process integration will determine key chemical and biological interactions between the various steps and will identify the best processes for pilot-plant trials in the PDU.

A primary benefit of the new AFUF, from the viewpoint of DOE and NREL, is the ability to conduct cooperative projects with industries interested in producing ethanol or other chemicals from biomass. Municipal solid waste is just one of many low cost feedstock opportunities. Forestry, agricultural, food processing, and other industries all have lignocellulosic waste streams that may be appropriate for biomass-to-ethanol production.

Warren Gretz, NREL

Amoco and NREL are using NREL's new process development unit (PDU) for pilot-plant testing of the biomass-to-ethanol technology.

Biomass Ethanol—A Plethora of Benefits

The NREL-Amoco CRADA offers tremendous promise for several reasons. Ethanol additives can immediately play a major role in alleviating automotive air pollution problems. In the longer run, neat ethanol fuel addresses many of the United States' major energy problems. "Home-grown" ethanol use reduces dependence on foreign oil and improves the balance of trade. Also, because ethanol is a "biofuel" made from renewable resources, the carbon dioxide released when it is burned is roughly balanced by the carbon dioxide consumed in photosynthesis as those

Warren Gretz, NREL

Planned feedstocks for the NREL-Amoco project are plentiful. Their conversion to ethanol could also reduce waste disposal problems.

resources are grown; therefore practically no contribution is made to global climate change.

DOE and NREL have set a goal of producing ethanol from biomass at a price that is competitive with gasoline. And they believe this could be the basis of a major new industry for the United States—one with great economic and environmental benefit. The role of ethanol made from starch will probably remain limited because of the limited availability of starchy food crops. But an industry producing ethanol from cellulosic material could tap specially grown energy crops such as grasses, as well as MSW and other waste biomass resources such as agricultural residues and forestry wastes. With this virtually unlimited feedstock supply, such an industry could potentially meet the entire U.S. demand for transportation fuel. Proving biomass-to-ethanol technology with MSW is particularly exciting because it also helps address landfill problems faced by communities across the country. Even considering the costs of separating out noncellulosic material, MSW should also be a particularly low-cost or even net-revenue feedstock, because "suppliers" might pay for its disposal.

Ethanol use reduces foreign oil dependence, creates jobs in the United States, improves the balance of trade, and maintains environmental quality.

The government partnership with Amoco provides an outstanding opportunity to accelerate the commercialization of federally funded technology innovations. Amoco already has much of the necessary fuel production facilities. It can also adjust base gasoline composition to blend well with ethanol, make ETBE, and market ethanol both as an oxygenated fuel additive and as a neat fuel. For Amoco, this is an opportunity to be at the forefront of a major new industry that fits well with its operations and strategic planning while helping to meet oxygenated fuel and alternative fuel mandates.

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