Conversion of Biomass to Fuel and Energy

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In 1991, biomass provided over 3.5 quads (a quad is a measure of energy that equals 1 quadrillion British Thermal Units, or Btu's) of the energy used in the United States. This was equivalent to the energy contained in 604 million barrels of oil which equals about 22 percent of annual U.S. oil imports.

Of this biomass energy:

- Half was used for direct heating applications in the industrial sector. For example, the wood and paper products industry uses residues from its operations to supply almost all heating and about half of the electricity needed in making their products.
- One-quarter was used for residential heating using wood and wood residues.
- Wood and biomass from agricultural processing operations and municipal solid wastes were used to generate three-quarters of a quad of electrical energy for utility companies.
- One billion gallons of ethanol, approximately 0.1 quad made primarily from corn, was used in transportation fuels.

Some of the technologies for using biomass for energy are mature, for example, burning wood for heating and generating electricity, and making ethanol from sugar and starch. Other technologies are just emerging, for example, converting cellulosic material from agricultural and forestry crops and residues into ethanol, and making biodiesel from oilseed crops and animal fats.

The potential for increasing the production of liquid fuels and energy from biomass is very large. Some estimates of this energy potential are as high as 26 quads per year. A significant expansion will depend, at least partially, upon the continued improvements in mature technologies and the development of cost-effective technologies for converting cellulosic material into ethanol, and oil from oilseed crops into biodiesel. Demand for these specific fuels and the costs of competing fuels will also influence the rate of expansion.

Ethanol From Corn—New Technologies

Although interest in ethanol as an automotive fuel began in the early 1900's, the modern fuel ethanol industry began with the oil shortage in the early 1970's. It has grown from virtually zero production to a billion gallons a year. More than 95 percent of the fuel ethanol produced in the United States uses corn as the feedstock. The remainder is produced from molasses; other grains such as milo, wheat, and barley; and industrial and food processing waste products such as potato culls and cheese whey.

In 1991, more than 370 million bushels of corn were used to produce ethanol. Corn is used because of its availability and high starch content. The two main methods use proven wet- and dry-milling grain processing technologies. Dry milling is based on traditional technology for the manufacture of potable alcohol, while the wet-milling process is based on the refining of corn to starch and fructose. Except for the initial separation process, the technology for the conversion of the starches to fuel ethanol is generally the same for both types of milling methods.

Dry Milling. In the dry-milling process, corn is milled and mixed with steam and enzymes to liquefy the starch component. The next step in the process converts the liquefied starch to sugars by adding additional enzymes. The sugars are fermented to ethanol using yeast. The mixture leaving the fermenter is distilled into 190-proof ethanol (95 percent ethanol and 5 percent water) and residues, which are called whole stillage. The ethanol is dehydrated to produce the 200-proof fuel grade. A process developed at Purdue University with USDA support uses corn grits to adsorb the water in the dehydration phase and reduces the cost of production by approximately 3-4 cents per gallon. Water is removed from the whole stillage by mechanical

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and drying processes to produce the distillers dried grains with solubles (DDGS), which is used as an animal feed.

Using current technology, dry mills can produce 2.6 gallons of fuel-grade ethanol and approximately 16.5 pounds of DDGS per bushel of corn. The carbon dioxide (CO_2) that is produced may also be collected from the fermentation tanks for use in the beverage and food processing industry. The three products are produced in approximately equal amounts, or one-third each of the initial weight of the bushel of corn.

Wet Milling. In the wet-milling process, corn is separated into the germ, fiber, gluten, and starch components. The first step in the separation process involves soaking or steeping the corn in a mixture of water and sulfur dioxide. The soft kernels are then milled to separate the germ from the starch. The germ is dried and the oil removed. The remaining slurry is screened to remove the fibers and then centrifuged to separate the gluten. The gluten is dried to produce corn gluten meal, which is used as an animal feed. The starch is liquefied and converted to sugar, which is fermented, distilled, and dehydrated to produce fuel-grade ethanol. The thin stillage from distillation is combined with water used for steeping and the solids removed by evaporation and added to the recovered fiber to produce corn gluten feed. The corn gluten feed is exported, primarily for dairy cattle feed.

Ethanol yields from wet milling are slightly lower than yields from dry-milling plants. In addition to about 2.5 gallons of ethanol from a bushel of corn, there are about 1.7 pounds of corn oil, 3 pounds of corn gluten meal (60 percent protein), 13 pounds of corn gluten feed (21 percent protein), and 17 pounds of carbon dioxide.

Dry-milling plants generally require lower initial investment than comparably sized wet-milling plants. However, the higher cost of the wet-milling plant may be offset by the higher value of the coproducts produced.

Promising Newer Technologies. Improvements have been made during the past 10 years in reducing the energy consumption for processing the corn into ethanol and in increasing the efficiency in converting the starch to sugar and fermenting the sugar into ethanol. In 1981, the energy required for processing exceeded 120,000 Btu's per gallon of ethanol produced, approximately 40,000 Btu's per gallon more than the energy content of a gallon of ethanol. In 1991, the energy consumption for processing averaged only 43,000 Btu's per gallon. The reductions in energy use have resulted from efficiency improvements throughout the entire plant, ranging from the cogeneration of electric power and steam to the use of corn grits and molecular sieves to remove the last 5 percent of the water in the ethanol.

Improved enzymes for converting the starch to sugars permit more efficient conversion at lower enzyme costs. New yeasts for fermentation have resulted in shorter fermentation times, higher levels of ethanol in the fermenter, lower residual sugars, and more sugars being converted. Higher ethanol concentrations have resulted in lower processing costs, as less water needs to be removed.

One new approach developed at a land-grant university for preparing corn to improve the efficiency of ethanol production is to inject gas to reduce the steeping time; this treatment of the corn kernels facilitates the separation of starch and protein from the other components, reducing the time required from approximately 40 hours to 8 hours.

The current method for converting the grain starch to glucose sugar involves a series of processes using enzymes. Research using membrane technology has shown that the time can be reduced from approximately 48 hours to about 5 hours.

Using the new tools of biotechnology, researchers are developing new yeasts that are both more resistant to the concentration of ethanol in the fermenter and more heat-tolerant. As indicated earlier, the higher the concentration the less water will have to be removed. Less energy will also be required for distillation because the beer broth will enter at a higher temperature.

New technology is also under development that will improve the removal of both the water from the ethanol and the solids from the water that has been removed from the DDGS or corn gluten feed. An open heat pump is used to take vapor from the top of a distillation column and mix it with the incoming beer broth in order to reduce the size of the heating plant and the overall energy requirements. The use of molecular sieves and pervaporation technology, which involves membranes operating in a vacuum, is being tested by a number of universities and private companies. These technologies could reduce the energy currently required for both distillation and drying of the DDGS and corn gluten feed.

Additional uses for the carbon dioxide and the solids (DDGS and corn gluten feed) are under development. Technology from the work on converting the cellulose and hemicellulose in energy crops is being used in studies to convert corn hulls to ethanol. Technology to convert carbon dioxide into higher value products, such as acetic acid, would reduce the percentage of ethanol production costs that would go to buying the corn or other raw material. Work is focused on improving the structure and functional properties of corn proteins for use in food products such as spaghetti, cornmeal, soy flour, and nonfat dry milk. Efforts are also being made to use the solids as feedstocks for high-volume industrial products such as biopesticides, building materials, glues, and solvents.

Ethanol From Cellulosic Material

Although ethanol is produced from starch-rich materials such as corn and sugarcane, ethanol can also be made from cellulosic biomass materials such as wood, forage, and wastes. Cellulosic materials are composed primarily of cellulose, hemicellulose, and a binding material called lignin. The process for producing ethanol from cellulosic materials is somewhat more complex than that for starch-rich materials, but the supply potential for cellulosic materials is greater.

The three primary cellulosic waste categories that offer the potential for ethanol production are agricultural residues, forestry residues, and municipal solid waste.

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Agricultural residues include stalks and other fibrous materials from food materials. Forestry residues include that material remaining after the harvest of timber (branches, small trees, foliage, and roots) as well as materials not used at sawmills for producing wood products. The final category, municipal solid waste, includes waste paper, yard wastes, and waste wood materials. Surprisingly, municipal solid waste is composed of 40 percent by weight cellulosic material. The potential for ethanol production of all this material could contribute about 4 quads to our energy needs.

Besides waste materials, the United States has enough existing and potential crop and forest land to produce 10-23 quads of cellulosic ethanol a year, depending on how the land is used. Land could be supplied from existing crop land which has excess agricultural capacity, potential crop land now in noncrop use, or forest land. These lands could be used specifically for growing cellulosic plants for conversion to ethanol. Additional research is needed to develop growing and harvesting strategies for wood or herbaceous high-productivity energy crops (HPEC) or short-rotation intensive culture (SRIC) tree plantations for the production of energy.

There are two general methods for producing ethanol from cellulosic material. The first is acid-catalyzed hydrolysis of biomass to sugars, followed by fermentation of the sugars to ethanol. The second method involves chemically or physically pretreating the biomass to yield a product from which the cellulose or hemicellulose can be hydrolyzed by enzymes to sugars. The sugar is then fermented to ethanol as in the acid hydrolysis method.

The production of ethanol from cellulosic residues is not new. Acid hydrolysis plants already existed in the United States during World War I for the production of ethanol. These plants closed after the war because of decreased supply and increased costs of material.

The chemistry for the production of cellulosic materials by hydrolysis has been known for over a century. The basic chemistry and processing are not very complex, but difficulties in practical application remain. The gathering of raw materials that are usually spread over large areas, the separation of contaminants (such as dirt, stones, and metals), prior to chemical processing, and the processing of a large variety of cellulosic material types are all problems that have slowed the development of ethanol production from cellulosic feedstocks.

Acid hydrolysis methods for producing ethanol from cellulosic materials can be divided into the dilute and concentrated acid methods. The dilute acid method of conversion involves subjecting cellulosic materials to a 0.5-1.0 percent sulfuric acid solution at temperatures from 150 to 180 °C. Concentrated acid hydrolysis using 40 percent hydrochloric or 72 percent sulfuric acid at 30 to 40 °C is also possible. The concentrated acids give higher yields because less sugar is decomposed at the lower temperatures, but the corrosive nature of the concentrated acids has resulted in high capital investment costs for this method.

Enzymatic hydrolysis requires pretreatment to render the material more accessible to the enzymes that enter into the hydrolysis reactions. Possible pretreatments include steam, milling, solvent, acids, and alkali. This process uses enzymes to break down the cellulose and hemicellulose into sugars at ambient or slightly above ambient temperatures. Although reaction rates are slower and the raw material must be pretreated, this process gives greater yields and fewer waste product disposal problems than acid hydrolysis. The enzymatic hydrolysis process is at a much earlier state of technological maturity, and major breakthroughs could make the process more economical than the acid hydrolysis process.

The use of ethanol from biomass has implications for global climate change. Carbon dioxide production comes from fermentation of the carbohydrate fraction of biomass to ethanol, combustion of unfermentable biomass fractions not converted to ethanol, and the combustion of ethanol itself. However, photosynthesis will remove carbon dioxide from the atmosphere during growth of energy crops, and the contribution of carbon dioxide to the atmosphere should be less than would result from using an equivalent amount of fossil fuel energy.

Although the cost of producing ethanol from cellulosic materials has been reduced, it is still higher than for gasoline. Significant innovations are needed to reduce the procuring and processing costs for cellulosic materials. Several promising areas of emphasis include:

- Harvesting methods for forest and herbaceous biomass materials
- Management of high-productivity energy crops and short-rotation intensive culture, including weed control, insect resistance, and genetically improved species
- Improvements in separation processes to remove contaminants from feedstock
- New and improved enzymes to increase the rate and conversion yield of cellulosic material to sugars

- Genetically engineered systems to improve breakdown to ethanol
- Pretreatments to increase hydrolysis efficiency
- Control over the quality and quantity of coproducts

The production of ethanol from cellulosic biomass is an emerging technology that ties directly into our country's National Energy Strategy. Successful innovations in procuring raw materials and processing cellulosic materials should make ethanol derived from cellulosic material an economic reality in the 21st century.

Biodiesel From Oilseed Crops

Biodiesel is a diesel-type fuel made from oils extracted from oilseeds and plants, or from animal fats, which can be used in unmodified diesel engines. The raw oils and fats must be modified by some chemical and/or thermal processes to reduce their viscosity and lower their high boiling point.

Many researchers have sought technologies to extract oil from seeds having high oil contents. Other researchers have evaluated the performance of the unprocessed oil in diesel engines. The interest is due, in a large degree, to the quantities of diesel fuel used in the critical sectors of the U.S. economy, such as production agriculture and the movement of food and other essential items by truck, rail, and boat. Currently, more than 25 billion gallons of diesel fuel are used annually in the United States. Production agriculture alone uses 2.5 billion gallons annually.

Evaluation of the unprocessed oil as a replacement and as a blend with diesel fuel revealed problems with engine deposits, ring sticking, injector coking, and increased viscosity of the lubricating oil. Results of research by USDA and several universities indicated that the problems were caused primarily by the high viscosity (thickness) and low volatility (high boiling point) of vegetable oils. The conclusion was that unprocessed oils may be used on a short-term basis both as a replacement and in blends; however, they are not dependable substitutes for long-term operations.

Researchers then began looking for ways to change the chemical and physical properties that would overcome the problems caused by the unprocessed oils. Three major technologies were developed and evaluated:

(1) Oils were blended with alcohols such as ethanol and methanol, plus a chemical additive (such as a detergent) to form stable microemulsions. An excellent blend was created, but too much carbon was formed on the interior parts of the engine.

(2) Techniques for cracking (heating) the unprocessed oil to reduce the boiling point were developed. The new chemical product contains acids that require a technology to neutralize them.

(3) The unprocessed oils were chemically converted (transesterified) to less complex chemicals known as fatty esters by combining the oils with alcohols, using a catalyst such as potassium hydroxide. Methyl and ethyl esters made from soybean and indus-

trial rapeseed oils using methanol or ethanol were found to have properties similar to diesel fuel and could be directly substituted in unmodified engines without significantly reducing performance or expected engine life.

A wide range of oilseed crops have been studied. We will discuss research conducted by scientists at the University of Idaho on industrial rapeseed oil to illustrate the process for making methyl ester.

A batch process using 40 gallons of rapeseed oil, 9 gallons of methanol, and 3.2 pounds of potassium hydroxide produces 40 gallons of methyl ester and almost 9 gallons of glycerine. The 40 gallons of oil were mechanically extracted from 860 pounds of seed. The 560 pounds of meal that remained contained 32 percent protein and over 10 percent residual oil.

In addition to the value of the meal as animal feed, the glycerine is valuable too, as it is used in various commercial products such as resins, cellophane, pharmaceuticals, and urethane foam. Natural glycerine is made from vegetable oils, and synthetic glycerine is made from propylene. Annually, over 10 million pounds are imported.

Several 200-hour engine tests, conducted in accordance with the Engine Manufacturer's Association specifications, indicated no significant adverse impacts on the engine; performance was similar to that of engines operating on diesel fuel. Limited emission testing in the United States and tests conducted in Europe with biodiesel and comparing biodiesel with diesel test results indicate: (a) little or no sulfur is emitted, (b) particulate and carbon monoxide are significantly reduced, (c) hydrocarbons are somewhat reduced, and (d) nitrogen oxides are similar.

Animal fat—and most any oilseed crop, including soybeans, rape, sunflowers, peanuts, and cotton—may be used to make biodiesel. Currently, biodiesel is not economically competitive with diesel fuels. Continued increases in the oilseed yield per acre and improved processing technology will help close the gap.

Direct Combustion of Biomass

The most common method of converting biomass to energy is direct burning or combustion. About 15 percent of the world's primary energy is derived from biomass, predominantly used in rural areas of developing countries. The use of biomass for energy has increased in the developing countries. In the United States today, more wood is used annually for energy production—from industrial waste to logs burning in the fireplace—than the amount used for the combined production of lumber and paper.

Although biomass from agricultural residues such as bagasse has been used to generate energy by direct combustion, most biomass energy is obtained from woody forest products. The surge in petroleum costs in the middle 1970's increased the use of biomass combustion to generate industrial energy, mainly in the forest products industry, which went from about 40 percent energy self-sufficiency to 70 percent in just a few years. The non-forest-based industries consume less than 5 percent of the wood energy used in the U.S. industrial sector.

The first step in the combustion of biomass is the evaporation of water that is present. Next, the volatile components, both combustible and noncombustible, are driven off at temperatures from 100 to 600 °C. Finally, the carbon in the biomass is oxidized.

The combustion process involves combining the carbon from the wood with oxygen to form carbon dioxide as well as combining the hydrogen from the wood with oxygen to form water. Heating values for biomass depend greatly on the initial amount of moisture in the material. Moisture reduces the heating value of biomass and thus biomass is usually dried or "seasoned" to improve its burning characteristics. For example, the heating value for dry wood is between 8,000 and 9,000 Btu per dry pound, which is about half that of gasoline. Wood with higher moisture content has a lower heating value.

Energy generated from biomass can be converted directly to heat, for example in a home fireplace; into process steam, such as for a steam-heated press for making plywood; or into electricity, such as in a processing plant. The basic equipment for using biomass energy for a variety of purposes has been available for many years, but as improved processing equipment comes on the market, new opportunities arise for more efficient use of biomass energy.

One application of biomass fuel is the generation of commercial electrical energy. Several commercial installations exist today, but these plants are small, 10-50 megawatts per year, and require considerable biomass for their power. For example, 500,000 wet tons of biomass per year are required to run one 50-megawatt plant. Continued availability of supply within a reasonable distance of the power plant is a major consideration for deciding whether to build a biomass-fired electrical power plant.

Biomass fuels have been mechanically converted to other fuel forms such as pellets, briquettes, and compressed logs. These forms of biomass fuel are expensive because of the extra steps required to form the fuel, and they are not used to any great extent in the United States.

The outlook for the use of forest biomass is good, but projections should be made with caution. The environmental effect of large-scale biomass operations must be determined and public concerns considered. Biomass can be effectively removed from many areas in this country with beneficial effects on the environment.

Besides the environmental considerations, many other areas of work in biomass combustion still need to be explored. The basic combustion process for converting biomass to energy still needs to be understood better, so that burning efficienciy can be improved and particulate emissions from burners can be reduced. Burning of waste materials containing contaminants needs to be explored so that direct combustion of municipal solid waste will be safe and the ash can be disposed of effectively. Better harvesting and transportation systems are needed to get the biomass to market as economically as possible.

Conclusions

We have made great progress in our development of technologies that convert biomass into energy. New technologies present the opportunity to expand our use of this resource more efficiently.

Making liquid transportation fuels from biomass economically and in large quantities could provide the Nation with a renewable source of fuel while reducing our dependence on imported oil. New technologies have made it possible to produce liquid fuels in large quantities, and in some cases the economics are becoming more favorable. However, the most important developments in technology and commercialization lie ahead. The greatest challenges are to learn how to utilize biomass material in a way that produces the maximum possible amount of fuel at the minimum cost. For the material that cannot be converted into fuel, we need to develop new and higher value uses.

Biomass fuel technologies can also help mitigate the problems with waste disposal that threaten our land and water resources. By converting some of this waste into liquid fuels, a critical need in the transportation sector is filled. When combustion is the more economical alternative, valuable electricity and process steam are produced. At the same time, emissions are reduced when compared to burning coal.

Biomass energy offers many advantages to us as a renewable, domestically produced source of liquid fuel, electricity, and process steam. However, research dollars must continue to be invested in the development of new technologies that improve the economic efficiency of biomass fuel sources. ❑

The Ethanol Market: Facing Challenges and Opportunities

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President George Bush has issued a challenge to America. On November 15, 1990, President Bush signed the Clean Air Act (CAA) of 1990—the first clean air bill in 13 years. This act targeted automobile fuel emissions as a major source of air pollution. The act mandates the use of cleaner burning fuels in problem areas to improve the Nation's mobile-source air pollution. Ethanol is one such fuel. Ethanol can help us reach our urban air-quality goals by reducing automobile emissions, the primary cause of air pollution in the United States.