Ethanol in Agriculture and the Environment

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The use of ethanol, or grain alcohol, a potential alternative high-octane fuel source, could help the United States reach three major policy goals: improved environmental quality, enhanced energy security, and stabilized farm income *(see box, "Ethanol as a Fuel")*. Recent events have refocused public attention to ethanol's role in these policy goals.

Last year, the 1990 Amendments to the Clean Air Act became law, requiring States to meet pollution standards. Ethanol, splash-blended with gasoline (splash-blended means it is mixed at the wholesaler), increases the amount of oxygen in gasoline, which reduces carbon monoxide emissions. The blend also reduces emissions of toxic chemicals that are known to cause cancer.

Also last year, Iraq's invasion of Kuwait disrupted world oil markets. Ethanol, produced from domestically grown grains, could displace some imported crude oil and refined oil products.

Finally, current U.S. budgetary concerns have led policy-makers to reduce Federal support to the agricultural sector. Ethanol creates an additional market for corn, reducing farm commodity program payments.

However, splash-blended ethanol has limitations. It increases some volatile organic compounds that are limited under the 1990 Amendments to the Clean Air Act. Also, the quantity of ethanol produced is unlikely to be sufficient to contribute significantly to national energy supplies in the near term. And to produce ethanol requires government tax exemptions to make it competitive with gasoline.

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The Current Fuel-Ethanol Industry

The current fuel-ethanol industry was created by a mix of Federal and State tax credits, excise tax exemptions, and loan programs. While producing about 825 million gallons of ethanol per year, the industry continues to depend on Federal and State tax credits and/or exemptions to remain viable. Before the Budget Reconciliation Act of 1990, an income tax credit of $0.60 per gallon of ethanol was allowed to producers and blenders of

Ethanol as a Fuel

Ethanol, which is sometimes referred to as grain alcohol, contains over 84,000 Btu's per gallon, roughly two-thirds as much energy as regular unleaded gasoline. According to researchers at the Oak Ridge National Laboratory, it takes almost 24,000 Btu's per gallon to grow the corn and another 49,000 Btu's to process it into ethanol. The by-product feed produced has an energy credit value of 8,000 Btu's per gallon, producing a positive energy balance of 19,000 Btu's per gallon. The liquid fuel energy balance is even greater when coal is used to fuel the ethanol processing plant.

The energy balance for ethanol is based on using it neat (or unblended) in current gasoline engines. Such use requires only minor modification to carburetors. However, straight ethanol causes poor ignition in cold weather and fewer miles per gallon.

A more common use for ethanol is to mix it with gasoline. The most common mixture is 10 percent ethanol and 90 percent gasoline and is often referred to as "gasohol." When mixed with gasoline, ethanol raises the fuel's octane rating and oxygen content. Raising the fuel's octane rating allows ethanol to replace high-cost carcinogenic aromatic compounds. Greater oxygen content improves combustion, which lowers carbon monoxide emissions.

Drawbacks to mixing ethanol with gasoline include potential increases in some volatile organic compounds, water contamination, and a slight—2 percent—decrease in mileage.

Ethanol does not mix well with diesel fuel. However, a diesel engine can be modified to burn unblended ethanol by adding spark plugs. The higher compression ratios of diesel engines take advantage of ethanol's high octane rating resulting in a more efficient ethanol use than a gasoline engine modified to burn unblended ethanol.

An innovative approach to burning ethanol in diesel engines is to add an ethanol mist into the engine air flow. Aspirated ethanol reduces diesel fuel consumption and the resulting carbon particle emissions, a major diesel pollutant. Another advantage of ethanol aspiration is that pure ethanol (200 proof) does not have to be used. Lower proof ethanol is less expensive and easier to produce than 200 proof ethanol. A disadvantage to aspirating ethanol can be increased engine wear.

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alcohol (190 proof or greater) for use as a highway motor vehicle fuel.

Alternatively, a $0.06 per gallon exemption from the Federal excise tax on gasoline, diesel fuel, or special motor fuels used to finance the Highway Trust Fund was allowed on the sale of alcohol-motor fuel mixtures that contained at least 10 percent alcohol. The minimum 10-percent blend requirement translates the $0.06 per gallon exemption into an effective $0.60 tax exemption per gallon of alcohol. Gasohol, 10 percent ethanol and 90 percent gasoline, qualifies for the exemption.

Under the Budget Reconciliation Act of 1990 that became effective December 31, 1990, the income tax credit was reduced to $0.54 per gallon (190 proof or greater) and the excise tax exemption was reduced to $0.054 per gallon (reducing the effective tax exemption to $0.54 per gallon). The income tax credit and the excise tax exemption have been extended to December 31, 2002, and September 30, 2003, respectively. In addition, the Budget Reconciliation Act of 1990 created a Small Producers Credit. The Small Producers Credit is an additional $0.10 per gallon income tax credit on the first 15 million gallons of ethanol and is available to producers with annual production capacity of up to 30 million gallons of ethanol.

Current Production Costs

Relatively high production cost is one reason why ethanol has not gained a larger share of the gasoline market *(see box, "The Real Cost of Petroleum")*. Most important are the prices of corn and ethanol by-products *(see box, "Ethanol Processing and By-products")*.

Over the past 10 years, corn prices moved from a high of $3.16 per bushel in 1981 to a low of $1.59 per bushel in 1987. The prices of ethanol by-products have also varied but not nearly as much as corn prices. With ethanol yields at 2.5 to 2.6 gallons per bushel of corn, the net cost of corn at a typical wet-mill varied from a high $0.70 per gallon in 1981 and 1984, to a low $0.13 per gallon in 1987 *(table 1)*.

The Real Cost of Petroleum

One of the disadvantages of ethanol is its high cost. With wholesale gasoline priced at approximately $0.70 per gallon, and ethanol at least $1.00 per gallon, it is not surprising that ethanol needs tax exemptions. However, some analysts conclude that the market price of gasoline does not equal its true cost to society.

When all costs are not included, consumption is greater than what is socially desired. To reflect an item's true cost in the marketplace, a tax can be levied. Alternatively, consumption can be decreased by subsidizing substitutes.

Some costs associated with gasoline include environmental damage, national security, and sustainability. Environmental damages include declining ambient air quality, the incidence of cancer from toxic fumes, and the potential for global warming. Large petroleum price increases due to world events, such as the Persian Gulf war, disrupt our economy and endanger our national security. Finally, petroleum is a finite resource. Today's petroleum consumption lessens the quantity available for tomorrow's consumers.

Estimating the cost of petroleum requires placing values on environmental quality, national security, and sustainability. Consequently, the costs associated with petroleum are subject to debate and vary among researcher with some estimates being much greater than the market price of petroleum.

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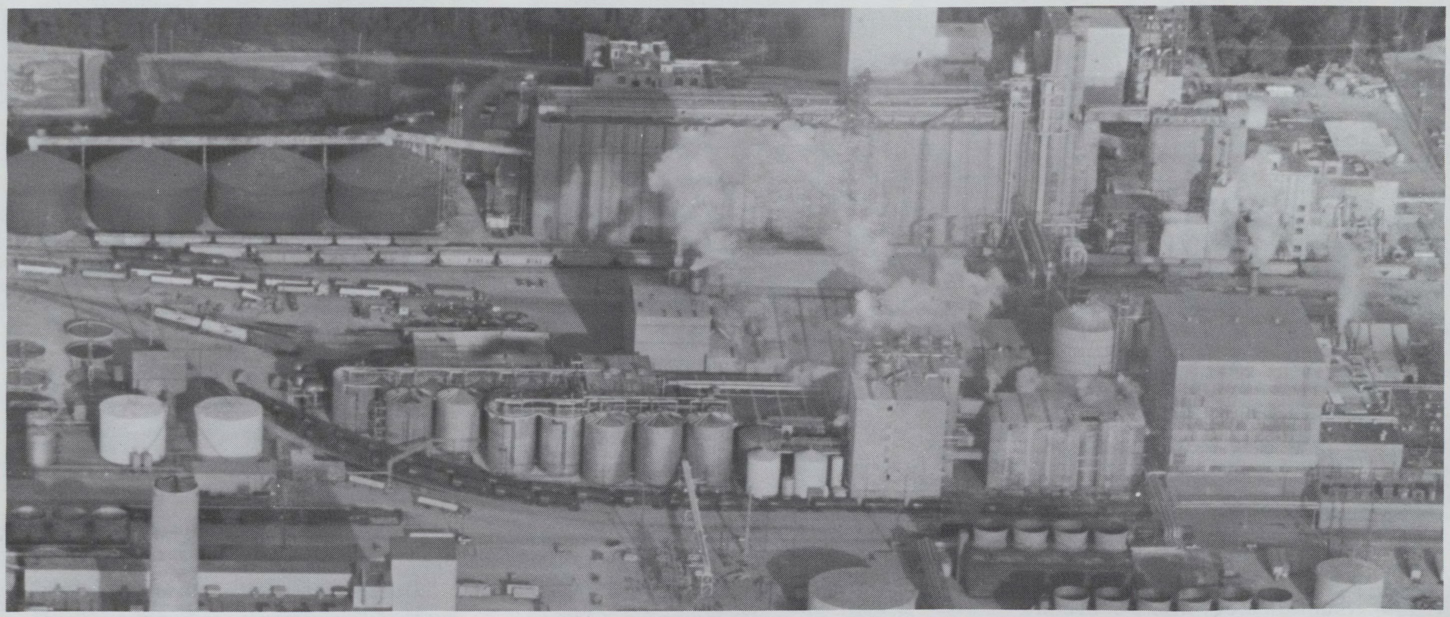
Table 1. By-Products Decrease Cost of Wet-Milling Corn Into Ethanol

	Corn price	By-product prices: Corn oil	By-product prices: Corn gluten feed	Corn gluten	Total by-product value		Net corn costs	
	$/bu.	*$/lb.*	*$/ton*	*$/ton*	*$/bu.*[1]	*Percent of corn price*	*$/bu.*	*$/gal.*[2]
1981	3.16	0.24	115.06	257.03	1.42	45	1.74	0.70
1982	2.48	0.24	113.53	235.31	1.38	56	1.10	0.44
1983	3.12	0.25	123.83	267.15	1.50	48	1.62	0.65
1984	3.11	0.30	94.05	243.12	1.37	44	1.74	0.70
1985	2.52	0.26	75.63	200.40	1.14	45	1.38	0.55
1986	1.95	0.18	94.78	213.92	1.16	59	0.79	0.32
1987	1.59	0.22	98.28	251.62	1.27	80	0.32	0.13
1988	2.36	0.24	122.01	306.14	1.52	64	0.84	0.34
1989	2.46	0.21	113.17	281.39	1.40	57	1.06	0.42
1990[3]	2.53	0.26	100.92	245.92	1.36	54	1.17	0.47

[1]Based on the following per bushel by-product yields: corn oil, 1.6 pounds; corn gluten feed, 12.5 pounds; and corn gluten meal, 2.5 pounds. [2]Based on 2.5 gallons of ethanol per bushel of corn. [3]First-third quarters.

Source: *Sugar and Sweeteners Situation and Outlook*, USDA, ERS, June and December 1990.



To reduce costs, wet-milling ethanol plants are often combined with corn sweetener production facilities.

Production costs vary considerably by plant size. Cash operating expenses include the costs of energy, ingredients excluding corn, personnel, management, insurance, and taxes. Using 1987 data, ERS researchers estimated that cash operating expenses for large plants ranged from about $0.40 to $0.59 per gallon of ethanol produced.

Estimated operating costs for small and medium sized plants vary in a wider range—from $0.32 to $0.65 per gallon. Small plants have higher costs because they are less able to take advantage of coal boiler cogeneration (steam and electricity) applications while meeting environmental regulations. Also, small plants have less efficient waste heat recovery and high per gallon personnel costs.

The investment required to build an ethanol plant can range from an estimated $1.00 to $2.50 per gallon of installed capacity. These investment expenditures translate into amortized capital costs ranging from $0.19 to $0.48 per gallon of ethanol. Where wet-mill capacity associated with corn fructose production exists, the fermentation and distillation capacity for ethanol production can be added at an estimated amortized capital cost of $0.19 to $0.29 per gallon. Converting abandoned ethanol plants or oil refineries have amortized capital costs between $0.33 to $0.38 per gallon while estimated amortized capital costs for new dry-mills with annual capacities of 40 million gallons or wet-mills with annual capacities of 100 million gallons are $0.38 to $0.48 per gallon of capacity.

The estimated full costs of production of ethanol (without the tax exemption) from a new stand-alone plant ranged from as high as $1.60 per gallon in 1981 and 1984 to $1.03 per gallon in 1987. An ethanol plant addition to an existing wet-mill could save as much as $0.20 per gallon.

Ethanol and Energy Security

The primary goal of U.S. energy policy is to ensure both short-term and long-term energy stability. Policy initiatives for short-term energy security are intended to minimize the effects on the U.S. economy of global energy market disruptions. Major policy initiatives for long-term energy security look to research and development to ensure timely commercial production of alternative fuels based on plentiful domestic resources.

Energy security also includes the ability of the United States to defend itself in time of war. A broader concern is to inhibit the ability of foreign countries to exert control over the United States by withholding or threatening to disrupt energy supplies. Using tax exemptions to encourage ethanol production from domestically produced grains reduces our dependence on foreign oil.

However, ethanol cannot be relied upon in the short term to play a significant role in meeting future energy needs. In 1988, ethanol production reached 825 million gallons per year. In the same year, the United States produced from domestic sources almost 3 billion barrels (124 billion gallons) of crude oil and imported almost 1.9 billion barrels (78 billion gallons). In addition, the United States imported almost 840 million barrels (35 billion gallons) of refined oil products. Therefore, a doubling of the ethanol industry will be inadequate to meet the total U.S. petroleum energy demand.

Even if domestic energy independence could be attained, international energy shocks would reduce global income and continue to affect the United States through international trade. The recent Iraq-Kuwait conflict highlights the importance of interrelated global markets. While less than 8 percent of U.S. crude oil imports were from Iraq and Kuwait, disruptions in world oil markets had a quick impact on U.S. markets. Also, higher energy prices reduced income in foreign countries, which decreased the demand for U.S. exports.

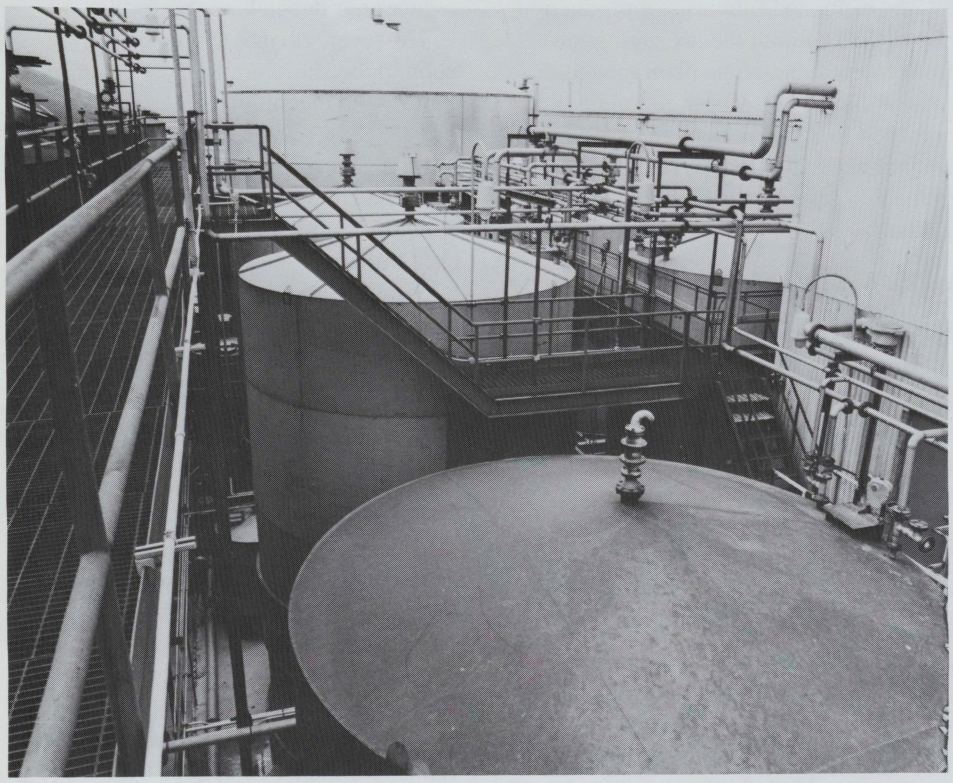
Ethanol and the Environment

Environmental concerns in many parts of the United States have renewed interest in reducing automobile emissions and led to passage of the Clean Air Act Amendments of 1990. The Amendments include a wide array of provisions designed to improve ambient air quality by requiring that concentrations of certain air pollutants not exceed standards set by the Environmental Protection Agency (EPA). States in areas where concentrations of those pollutants exceed the standards are required to develop plans to control emission sources to meet the standards.

Of the pollutants listed, ozone and carbon monoxide are furthest from meeting the desired standards. Cleaner, reformulated gasoline is mandated in the nine cities (Baltimore, Chicago, Hartford, Houston, Milwaukee, New York, Philadelphia, Los Angeles, and San Diego) with the most severe ozone pollution in 1990. Reformulated gasoline is required, by 1995, to have 15 percent lower emissions of volatile organic compounds (VOC's such as hydrocarbons and nitrogen oxides that react with sunlight to produce ozone) compared with conventional gasoline.

Starting in 1992, the Act also establishes an oxygen content level of 2.7 percent in gasoline in the 44 cities with serious carbon monoxide pollution. EPA attributes 66 percent of all carbon monoxide emissions (80 percent in many urban areas) to imperfect combustion in motor vehicles.

One answer to the problem of imperfect combustion is to increase the amount of oxygen in gasoline. Adding ethanol, ETBE (ethyl tertiary butyl ether which is 42 percent ethanol), methanol (wood alcohol), or MTBE (methyl tertiary butyl ether which is 35 percent methanol) to gasoline creates "oxygenated" blends.



Starch from grains is fermented into ethanol fuel.

Oxygenated blends have a greater air/fuel ratio which improves the combustion of gasoline and therefore reduces exhaust emissions including carbon monoxide. Blended fuels are similar to straight gasoline, which enables vehicles to use them without changing existing engine designs.

Carbon dioxide emissions from motor vehicles are also potentially serious environmental problems. Carbon dioxide may contribute to the "greenhouse effect" of trapping the sun's heat and causing the earth's temperature to rise. Because corn absorbs carbon dioxide as it grows, replacing gasoline with ethanol processed from corn by-products reduces the quantity of carbon dioxide added to the atmosphere.

Burning gasoline creates environmental health problems. At one time, lead was used to raise the octane level of gasoline. Lead was phased out because of health problems associated with lead poisoning.

To replace lead as an octane enhancer, gasoline refiners often use aromatic compounds such as benzene, toluene, and xylene. But aromatic compounds are toxic chemicals, and EPA estimates that 56 percent of cancer incidence due to toxic chemicals comes from gasoline emissions. Over time, the amount of aromatic compounds in gasoline has increased as the demand for high octane (premium) gasoline has risen. Using splash-blended ethanol as an octane enhancer, instead of aromatic compounds, would reduce the quantity of toxic chemicals released from car tailpipes and gasoline filling station pumps.

A potentially negative environmental impact of adding splash-blended ethanol to gasoline is increased fuel volatility, which increases the amount of ozone-causing evaporative hydrocarbon emissions. Evaporative emissions from ethanol-blended fuels can be reduced by reformulating the gasoline to have a lower vapor pressure or by converting the ethanol into ETBE before blending with gasoline.

Ethanol and U.S. Agriculture

The amount of production of ethanol depends on commodity market conditions, the nature of farm programs, and the size of the ethanol industry. Ethanol creates an additional market outlet for corn, which increases the price of corn. The amount of the price increase depends upon how much corn is demanded by ethanol producers and the ability and willingness of farmers to shift idle acres and land used for competing crops into the production of corn. Depending on the government incentives in place, farmers would be expected to increase their plantings of corn at the expense of soybeans.

Farmers would make the shift for two reasons. First, returns to corn relative to other crops would be higher because of rising corn prices. Second, high protein animal feeds, which are a by-product of ethanol production, would cause the price of soybeans to fall *(see box, "Ethanol Processing and By-products")*.

The livestock sector is also affected by ethanol production because feed energy (corn) prices rise relative to high protein feed prices. Because livestock rations contain primarily energy feeds, ethanol production can increase the cost of feeding livestock.

A moderate expansion in ethanol production would likely have a small effect on consumer prices. ERS researchers estimate that a 2.7-billion gallon ethanol program could cost consumers an additional $150 million per year in food expenditures while a 3.4-billion gallon program would cost consumers as much as $350 million.

Increases in consumer prices could be minimized if the set-aside requirements associated with current farm programs were relaxed. In 1990, for example, 26 million acres of cropland were idled

Ethanol Processing and By-products

Two similar technologies for producing ethanol are now in commercial operation: dry- and wet-milling. In most ethanol producing dry-mills, corn is ground, slurried with water, and cooked. Enzymes convert the starch to sugar and yeasts ferment the sugars to produce beer. The beer, which contains alcohol, water, and dissolved solids, is separated. The alcohol and water are then distilled and dehydrated to create anhydrous (without water or 200 proof) ethanol. The remaining solid solubles are dried and sold as dried distillers grains and solubles (DDGS). DDGS is a high-protein livestock feed (27 percent crude protein with about the same feed energy as corn).

The primary difference in the wet-milling process is that the individual portions of the corn kernel are separated prior to cooking, producing an almost pure starch. The starch is converted to sugars, which are then fermented into ethanol. (Because an ethanol wet-milling plant is identical to a corn sweetener plant through the starch production phase, the two facilities have often been combined.) The by-products associated with a wet-milling process include corn oil and 2 high protein feeds, corn gluten feed (20 to 21 percent crude protein), and corn gluten meal (60 percent crude protein).

Under both processes, about 2.5 to 2.6 gallons of ethanol are produced from each bushel of corn. The per bushel by-product yields are 18 pounds of DDGS if dry-milled, or 12.5 pounds of corn gluten feed, 2.5 pounds of corn gluten meal, and 1.6 pounds of corn oil if wet-milled. Both processes also generate about equal amounts of carbon dioxide.

Use of these by-products for feed limits the influence of ethanol production on agriculture. For example, the protein component of DDGS produced from an acre of corn processed into ethanol replaces the soybean meal produced from 0.6 of an acre of soybeans. Because DDGS has a lower protein content than soybean meal, the substitution of DDGS for soybean meal results in extra feed energy. This additional feed energy replaces corn from 0.2 acres. Therefore, the initial affects of producing ethanol on the agricultural sector are minimal because 80 percent of the cropland for ethanol production can come from released soybean and corn feed production.

Ethanol by-product feeds are limited in swine and poultry feed rations and can substitute for only a portion of the soybean meal. Cattle don't face the same limitations and much of their diet can consist of by-product feeds.

Greater increases in agricultural prices will occur when the by-product feeds can no longer substitute for soybean meal in swine and poultry rations and have replaced all of the soybean meal in cattle rations. When substitution for soybean meal is no longer possible, the by-product feeds are valued solely for their feed energy in cattle rations and replace the feed from only one-third of an acre of corn.

The remaining acreage must come from traditional agricultural uses. Additional ethanol output requires substantially higher corn prices to entice farmers to shift land to corn (ethanol) production. And as land is shifted to corn from other crops, prices of other crops rise. Also as corn prices increase, livestock feed costs go up. Poultry, the most efficient grain converter, is the least affected.

The nation's largest ethanol producer, Archer Daniels Midland (ADM) Company, uses the wet-milling process to produce its ethanol. To improve the economics of processing corn into ethanol, ADM has developed fluid bed cogeneration (steam and electricity) boilers that burn high sulfur coal and meet EPA air quality standards. ADM is experimenting with mixing used tires and coal. Therefore ethanol processing could turn the nation's abundant coal supply and environmentally hard-to-dispose-of used tires into fuel for cars.

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under annual Federal acreage reduction programs with 10 million acres idled under the corn program. The acres idled under the corn program alone represent over 2.5 billion gallons of potential ethanol.

Future Ethanol Processing

Alternative ethanol agricultural feedstocks such as potatoes, sweet potatoes, Jerusalem artichokes, sugar beets, fodder beets, sweet sorghum, and grains other than corn may prove beneficial in the longer term. Use of these crops for ethanol does not present any particular technological hurdle. Should corn prices rise, some of these crops may prove to be cheaper feedstocks because they can be grown on a broader range of lands and in climates unsuited for corn production. Bioengineering and traditional plant breeding technologies that increase per acre yields or increase starch and sugar contents of corn and other crops also offer the potential for lower cost ethanol through reductions in feedstock costs. Any advances in crops that reduce production costs or increase starch yield would lower ethanol feedstock costs.

Processes to break down the various types of cellulosic biomass materials into sugars that can then be fermented are an active research area. Breakthroughs in biomass pretreatment and conversion would allow higher yields from grains because part of the grain crop is cellulose. Also, herbaceous plant matter could be used. For example, crops such as alfalfa, energy sorghum, and switchgrass, as well as cellulosic material such as corn stover or bagasse, could be fermented. These technologies could ultimately allow ethanol production from woody plants and a broader range of organic wastes.

The Department of Energy (DOE) estimates potential ethanol production costs from cellulose feedstocks, such as grasses and fast growing trees, at $1.00 to $1.35 per gallon. This estimate includes carbon dioxide and the energy value of unconverted cellulose as by-product credits. DOE hopes to reduce ethanol production costs from cellulose to as little as $0.60 per gallon by 1998.

Cellulose conversion and processing of renewable resources (biomass) into oxygenated fuels and chemicals is the next major development in agriculture. The timeframe over which this will occur depends on the level of research and development in the growth, harvesting, transportation, storage, processing, fermentation, and final product recovery related to cellulosic materials. Research on the biochemical, chemical, and microbial transformation of renewables into value-added by-products is critical. Some of the key developments will be: microorganisms which efficiently ferment a broad range of sugars in addition to glucose; technology to readily convert biomass materials into processed cellulose, lignin, hemicellulose, and by-product streams; chemical modification of cellulosic materials to products that supplant current materials derived from other sources such as petroleum; and development of an industrial infrastructure based on biomass resources.

Many potential benefits could result from an industrial infrastructure based on cellulosic biomass feedstocks. Rural communities could benefit from the processing of biomass feedstocks into industrial products through increased employment and tax base. Farmers could benefit by having a wider selection of profitable crops. More crop choices make it easier to develop rotations that minimize chemical inputs. Some of the crop choices could be pasture grasses which would reduce farmers' incentive to plant row-crops on highly erodible land.

The focus of near- and long-term ethanol research and development differs to a degree. Much of the near-term research and development efforts have focused on the narrower context of the ethanol production facility itself. To examine the potential of the industry beyond a role as a user of surplus corn and other grains, research is being done by USDA on ethanol production technologies capable of using a broader set of feedstocks, and the development of markets for by-products from both new and existing technologies. ■

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