Demand Drivers and Price Supports for Bioethanol Use as Fuel in the United States: A Brief Review

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Abstract

Fuel ethanol, especially cellulosic ethanol, is likely to play an important role in renewable fuel development. This article reviews the main factors that currently drive fuel ethanol demand in the United States. In the short term, the phaseout of methyl tertiary butyl ether (MTBE) is important. In the long run, federal and state price support policies will play a dominant role in fuel ethanol demand. Both major demand factors and the current status of cellulosic ethanol manufacture are discussed. The current state of technology and the high capital cost for cellulosic ethanol production when compared with corn-based ethanol are major barriers to expanding the markets.

Fuel ethanol, sometimes termed *bioethanol,* has a very long history of use as a motor fuel in the United States. Research into ethanol use as a fuel began long before Henry Ford announced that ethanol was the ''fuel of the future'' in 1925 (Kovarik 1998). Interest waned until the 1980s, when state and local policy initiatives and other factors generated increases in both production and consumption. Currently, most fuel ethanol in the United States is blended with gasoline at up to 10 percent by volume to produce a fuel called E10. All cars and light trucks built for the US market since the late 1970s can run on E10 (Gross 2007). Further, flexible fuel vehicles (FFV) have been introduced into the US market. The 7.1 million FFVs in use can run on as much as 85 percent ethanol (E85; Energy Information Administration [EIA] 2008).

The production of fuel ethanol in the United States has grown rapidly (Fig. 1). As of 2009, US fuel ethanol production reached 10.75 billion gallons (here and throughout, billion gallons refers to 10^9 gallons; Renewable Fuels Association [RFA] 2010a). In 2007, the approximate gasoline consumption was 142 billion gallons, which includes the volume added by blending with ethanol (EIA 2008). As of 2007, the fuel ethanol consumption in the US was 6.85 billion gallons, which accounts for about 4.8 percent of the combined gasoline ''pool'' consisting of gasoline plus fuel ethanol. Currently nearly all of the fuel ethanol in the US is produced from corn feedstocks (RFA 2010b).

Demand for Biofuels in the United States

Cellulosic ethanol mandates

Like corn-based ethanol, cellulosic ethanol made from wood and other agricultural wastes has a long and convoluted history (Kovarik 1998). Much of the criticism against cellulosic ethanol has been, and continues to be, associated with low process yields and high production costs. Despite criticism, cellulosic ethanol is widely recognized as one of the most promising ways to meet renewable fuels mandates without competing with food crops.

Cellulosic ethanol is considered an advanced biofuel and can be produced using several methods with a wide variety of cellulosic biomass feedstocks including agricultural plants, forest waste, and energy crops (Greer 2005). The Energy Independence and Security Act (EISA) of 2007 mandates usage (Fig. 2), and a portion of that must be from cellulosic ethanol by 2022 as discussed below (EIA 2009). Furthermore, EISA requires we begin to use cellulosic ethanol in 2013 (Yacobucci 2008a).

MTBE replacement

The primary use, and therefore demand, for biofuels in the United States has been as a replacement for methyl tertiary butyl ether (MTBE) in motor fuels. MTBE, a petroleum-derived additive, was commonly used as an oxygenate, an octane booster, and a volume extender (EIA 2010). MTBE, although not considered a carcinogen,

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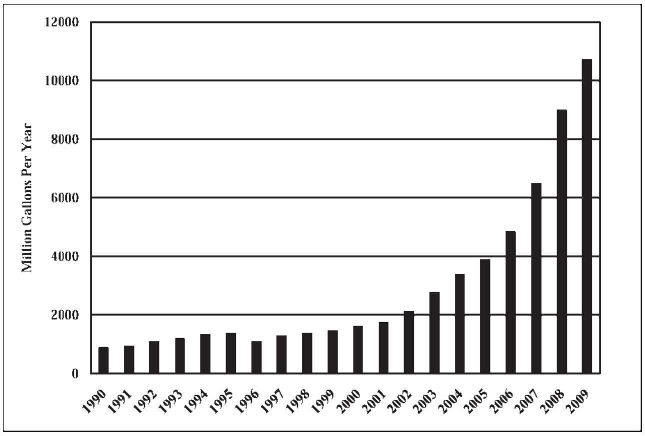

Figure 1.—Fuel ethanol production trends in the United States (sources: RFA 2010a, 2010b).

readily pollutes ground water, and for public health reasons, the use of MTBE has been banned or is being phased out in 25 states (Table 1; US Environmental Protection Agency [EPA] 2007, EIA 2010).

The use of MTBE has to be placed in context. There are three broad categories of gasoline sold in the US market, termed oxygenated gasoline, reformulated gasoline (RFG), and conventional gasoline. The Clean Air Act Amendments of 1990 require specific levels of oxygenated gasoline be used in certain areas. The extent of oxygenation depends on the EPA's assessment of air pollutant levels, and the differences have led to two specific programs (EPA 2010).

The first program is termed the wintertime oxygenated gasoline program or, more simply, the oxygenated gasoline program. Originally implemented in November 1992, it requires 2.7 percent oxygen in gasoline by weight, which is equivalent to 15.0 percent MTBE or 7.4 percent ethanol by volume. Ethanol is the primary oxygenator used in this program.

The second program is titled the ''year-round reformulated gasoline'' RFG program or, more simply, the reformulated gas program and was implemented in December 1994. The RFG program is used in cities with the worst smog problems. The RFG program requires 2.1 percent oxygen in gasoline by weight, which is equivalent to 11.7 percent MTBE or 5.8 percent ethanol by volume.

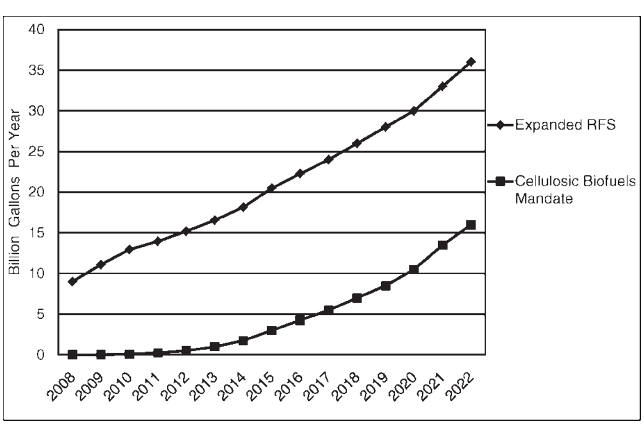

Figure 2.—Energy Independence and Security Act of 2007 mandates from 2008 to 2022 (source: Newcomb 2009).

Table 1.—MTBE status, by state, in alphabetical order.[a]

State	Status of ban
Arizona	MTBE banned from Jan 2005
California	MTBE banned from Jan 2004
Colorado	MTBE banned from Apr 2002
Connecticut	MTBE banned from Oct 2003
Illinois	MTBE limited to 0.5% by volume from Jul 2004
Indiana	MTBE limited to 0.5% by volume from Jul 2004
Iowa	MTBE limited to 0.5% by volume from Feb 2000
Kansas	MTBE limited to 0.5% by volume from Jul 2004
Kentucky	MTBE ban from Jan 2006
Maine	MTBE limited to 0.5% by volume from Jan 2007
Montana	No more than trace amounts of MTBE in fuel after Jan 2006
Michigan	MTBE prohibited from Jun 2003
Minnesota	MTBE prohibited from Jul 2005
Missouri	MTBE limited to 0.5% by volume from Jul 2005
Nebraska	MTBE limited to 1% by volume from Jul 2000
New Hampshire	MTBE banned from Jan 2007
New Jersey	MTBE banned from Jan 2009
New York	MTBE banned from Jan 2004
North Carolina	MTBE banned from Jan 2008
Ohio	MTBE limited to 0.5% by volume from Jul 2005
Rhode Island	Complete MTBE ban to take effect by Jun 2007
South Dakota	MTBE limited to 0.5% by volume from Jul 2001
Vermont	MTBE banned from Jan 2007
Washington	MTBE banned from Dec 2003
Wisconsin	MTBE limited to 0.5% by volume from Aug 2004

[a] Sources: EPA 2007, EIA 2008.

MTBE has been the main oxygenator in RFG in cities outside of the Midwest, but that is changing for the reasons cited above. At this time, about 30 percent of gasoline nationwide is RFG and 87 percent of RFG contains some MTBE (EPA 2010).

Conventional gasoline may also contain MTBE to meet octane needs. However, the percentage of MTBE volume in conventional gasoline varies. For example, according to surveys by the Maine Department of Environment Protection, the average MTBE in gasoline sold in Maine in 2001 was 2.4 percent by volume. Similarly, the Michigan Department of Agriculture claimed that MTBE was detected in only 17 percent of samples tested and comprised an average 4.75 percent by volume (Lidderdale 2003).

Five states have a significant direct effect on both MTBE and gasoline markets: California, Connecticut, Kentucky, Missouri, and New York. These five states consumed about 50 percent of the MTBE blended into RFG and oxygenated gasoline and 44 percent of all MTBE consumed in the United States (Lidderdale 2003). The latter number could be higher since it does not include the volume of MTBE blended into conventional gasoline.

Currently, ethanol is the only feasible choice to replace MTBE as an oxygenator. Furthermore, because ethanol contains more oxygen than MTBE, only about half as much ethanol (by volume) is needed for RFG (Lidderdale 2003). The rapid switch from MTBE to ethanol has impacted the gasoline and fuel ethanol markets in several ways. RFG is generally blended with the minimum required volume of ethanol or MTBE to minimize costs. Consequently, replacing MTBE with ethanol will result in a reduction of RFG volume. MTBE usage (Fig. 3) reached its peak around 1999 and declined rapidly after 2001 after some state bans took effect. Conversely, fuel ethanol consumption increased

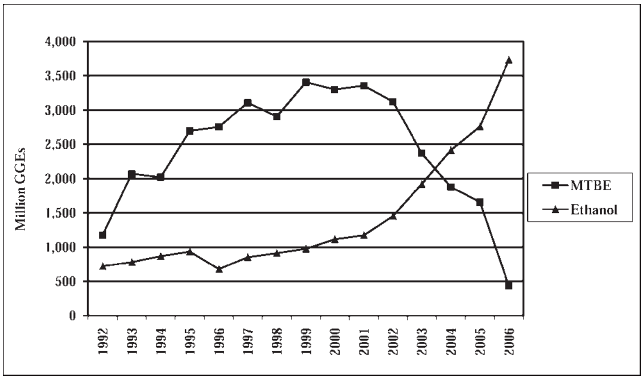

Figure 3.—US oxygenate consumption by year 1992 to 2006. GGE = gallon gasoline equivalent, a common unit of comparison (source: Alternative Fuels and Advanced Vehicles Data Center 2008).

very quickly after 2001 as shown in Figure 1 (RFA 2010a). Finally, since the spring of 2006, all major refiners have largely removed MTBE from use due to the environmental concerns mentioned above (Yacobucci 2008a). Therefore, demand for bioethanol has become, in a matter of a few years, closely linked to demand for motor fuel consumption—a non–policy-based demand driver that exists today.

Replacement of MTBE by ethanol in gasoline replaces some of the lost volume caused by MTBE removal and affects both oxygen content and octane level. However, ethanol has several technical issues that may detract from its expanded use. First, ethanol substitution increases vapor pressure when compared with gasoline blended with MTBE, making some ingredients of the gasoline blend less stable. Some low-cost, high vapor pressure components, such as butane and pentane, have to be removed from the blend, which make it more difficult and expensive to produce ethanol-based RFG. Second, ethanol is likely to separate from gasoline if stored for a long period (Lidderdale 2003). Third, when exposed to water vapor, ethanol–gasoline blends tend to absorb water into solution and may be unusable (Lidderdale 2003). Finally, E10 has 3.3 percent less energy per gallon compared with conventional gasoline. E85, which averages 74 percent ethanol by volume, has 24.7 percent less energy per gallon than conventional gasoline (EIA 2007). In practical terms, and according to the EIA, which assumes that engine thermal efficiency is still the same regardless of the fuel type (i.e., E10, E85, conventional gasoline), it will require about 1.03 gallons of E10 or 1.33 gallons of E85 for a vehicle to travel the same distance it would travel with a gallon of conventional gasoline (Yacobucci 2008a).

Policy Initiatives Affecting Bioethanol Demand and Production

In order to promote the use of biofuels, the United States has enacted a series of federal policies beneficial to the ethanol industry. These federal policies included tax credits, import tariffs, and mandates for use.

The initial ethanol policy of 1978 (Table 2) was aimed at developing alternative and renewable energy supplies in view of the embargo of 1973 and influenced the 1979 embargo policy (Yacobucci 2008a). The Energy Policy Act of 1978 provided a subsidy of \$0.40 per gallon for the ethanol blender (Tyner 2007). Since 1978, the ethanol subsidy has ranged between \$0.40 and \$0.60 per gallon, and the history of subsidy changes and major legislation is shown in Table 3 (Tyner 2007, Yacobucci 2008a). As of January 2009, the federal tax credit that totaled \$0.51 per gallon was reduced to \$0.45 for 1 gallon of pure ethanol. It is currently authorized at that subsidy level through December 31, 2010 (American Coalition for Ethanol 2010).

In addition to the federal blending credit subsidy, there also are some other federal and state subsidies. At least 23 states provide ethanol-linked incentives that are usually related to production. For example, Minnesota provides \$0.20 per gallon production tax credit for the ethanol producer but includes a cap of \$3 million per producer per year. Furthermore, 29 states offer grants or subsidized credit and tax concessions related to capital investment for ethanol production (Koplow 2007). Tyner (2007) estimated that the total subsidy available for ethanol in 2006 ranged between \$1.05 and \$1.38 per gallon. Federal and state subsidies, in total, provided \$5.1 to \$6.8 billion for ethanol annually as of

Table 2.—History of US ethanol subsidy legislation.[a]

Year	Legislation	Subsidy provided
1978	Energy Tax Act of 1978	\$0.40 per gallon of ethanol tax exemption on the \$0.04 gasoline excise tax
1982	Surface Transportation Assistance Act	Increased tax exemption to \$0.50 per gallon of ethanol and increased the gasoline excise tax to \$0.09 per gallon
1984	Tax Reform Act	Increased tax exemption to \$0.6 per gallon
1988	Alternative Motor Fuels Act	Created research and development programs and provided fuel economy credits to automakers
1990	Omnibus Budget Reconciliation Act	Ethanol tax incentive extended to 2000 but decreased to \$0.54 per gallon of ethanol
1990	Clean Air Act as amended	Acknowledged contribution of motor fuels to air pollution
1992	Energy Policy Act	Tax deductions allowed on vehicles that could run on E85
1998	Transportation Efficiency Act of the 21st Century	Ethanol subsidies extended through 2007 but reduced to \$0.51 per gallon of ethanol by 2005
2004	Jobs Creation Act	Changed the mechanism of the ethanol subsidy to a blender tax credit instead of the previous excise tax exemption. Also extended the ethanol tax exemption to 2010
2005	Energy Policy Act	Established the Renewable Fuel Standard starting at 4 billion gallons in 2006 and rising to 7.5 billion in 2012
2007	The Energy Independence and Security Act	Requiring the use of 9.0 billion gallons of renewable fuel in 2008, increasing to 36 billion gallons in 2022
2009	The Volumetric Ethanol Excise Tax Credit	As of Jan 1, 2009, the original tax credit was reduced to \$0.45 gallon pure ethanol.

[a] Sources: Tyner 2007, Yacobucci 2008b, American Coalition for Ethanol 2010.

Table 3.—DOE investment in cellulosic ethanol projects.[a]

Company	Location	Investment amount	Current status (second quarter, 2010)
Abengoa Bioenergy Biomass of Kansas, LLC, of Chesterfield	Kansas, Missouri	$35.5 million	First phase completed; a 1.5 metric ton/d biomass refinery pilot plant has been in operation since Sep 2007
ALICO, Inc. of LaBelle	Florida	Up to $33 million	Plant was canceled
BlueFire Ethanol, Inc. of Irvine	California, Mississippi	Up to $40 million	DOE increased the funding to $88 million for Phase II construction at Fulton, MS
POET (formerly Broin Companies)	South Dakota	Up to $80 million	Under construction 2009–2011, biorefinery startup expected 2011
Iogen Biorefinery Partners, LLC, of Arlington	Virginia	Up to $80 million	Plant canceled; seeking financial support from Canadian government
Range Fuels (formerly Kergy Inc.) of Broomfield	Colorado	Up to $76 million	First phase in Soperton, GA, is scheduled to be completed soon; expected production of less than 10 million gal/y to follow in the second quarter of 2010

[a] Sources: RFA 2010b and personal communication.

2005. According to an EIA forecast, the federal and state subsidies plus purchase mandates and new exemptions will reach $7.9 billion by 2010 (Koplow 2007).

The use of fuel ethanol in the United States is regulated by three broad legal policies: the Clean Air Act of 1970, as amended in 1990; the Energy Policy Act of 2005; and the Energy Independence and Security Act (EISA) of 2007. The amended Clean Air Act of 1990 imposed mandatory minimum oxygen content levels in some areas as described above.

The Energy Policy Act of 2005 (Public Law 109-58), which created the Renewable Fuel Standard (RFS), removed the oxygenate requirement but imposed a mandate to use at least 4.0 billion gallons of renewable fuel in 2006, increasing to 7.5 billion gallons by 2012 (Yacobucci 2008a). Further, ethanol from cellulosic feedstocks was granted extra credit—a gallon of cellulosic ethanol is counted as 2.5 gallons of renewable fuel under the policy. Also, the policy requires that 250 million gallons of cellulosic ethanol be blended in gasoline annually starting in 2013. The Energy Independence and Security Act (EISA) of 2007 (Public Law 110-140) significantly expanded the target, requiring the use of 9.0 billion gallons of renewable fuel in 2008, increasing to 36 billion gallons in 2022. Of that mandate, at least 16 billion gallons is expected to come from cellulosic ethanol by 2022 (Yacobucci 2008a).

Imports of Bioethanol into the United States

The relatively high price of corn-based ethanol and the increased demand for ethanol in the United States have necessitated importing ethanol from Brazil and other countries to meet the demand. The import volume ranged from 450 to 653 million gallons per year from 2006 to 2009 (RFA 2010b). Imports are costly due to duties and tariffs. Currently, most ethanol imports are subject to a 2.5 percent ad valorem tariff. In order to offset the blenders' ethanol credit received by imported ethanol and to ensure that tax credits are not used to invest in foreign ethanol production, US ethanol imports from other countries are also subjected to a $0.54 per gallon secondary duty (American Coalition for Ethanol 2010).

The United States Congress has created some preferential trade promotion programs, such as the Caribbean Basin Initiative (CBI) and the Andean Trade Preference Act, that allow ethanol produced in those countries to enter the United States duty free (Yacobucci 2008b). The CBI includes Antigua and Barbuda, Aruba, the Bahamas, Barbados, Belize, the British Virgin Islands, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, Netherlands Antilles, Panama, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago. The Andean Trade Preference Act includes Bolivia, Colombia, Ecuador, and Peru. Ethanol producers in those countries avoid the secondary duty as long as the ethanol is produced within their countries. However, those countries actually manufacture very little, if any, ethanol from feedstocks. Rather, to meet the requirements of the CBI and the Andean Trade Act, ethanol is imported from a country, such as Brazil, dehydrated, and then shipped to the United States. Under current regulations, total imports into the United States are limited by a quota to a maximum of seven percent of total domestic ethanol production (Yacobucci 2008b; RFA 2010b).

Some Impacts of US Ethanol Policies

According to an economic analysis by the Food and Agriculture Policy Research Institute, which is a joint effort of Iowa State University's Center for Agricultural and Rural Development (CARD) and the University of Missouri–Columbia, allowing the existing tax credit to expire would lead to annual corn ethanol reduction of 80 percent from 1998 levels of production (Yacobucci 2008a).

According to Meyer (2009), who focused on corn ethanol, the US ethanol support policies have significant impacts on ethanol production, corn price, and ethanol imports. Using existing ethanol policies ($0.45 blenders' ethanol credit and stiff import tariffs) as a base during the period 2009 through 2018, they conclude:

- If the ethanol tax credit expires, the ethanol production profits will decline; however ethanol production still must grow to meet mandated levels of use. As a result, corn prices will fall by 0.6 percent in the period of 2011 through 2018.
- If the tariff expires, domestic corn-based production will decline because of cheaper imports of sugar-based ethanol. The price of corn would fall by 2.8 percent as a result of decreased domestic corn-based ethanol production.
- Reducing the ethanol use mandate by 1 billion gallons will reduce average ethanol production by 0.5 billion gallons, and the corn price would drop by one percent. Elimination of the ethanol use mandate (under the RFS) would lead to a reduction in ethanol production of 1.91

Table 4.—US cellulosic ethanol projects under development and construction.[a]

Company	Location	Stated production capacity	Feed stock	Current status (second quarter, 2010)
Abengoa	York, NE Hugoton, KS	11.6 mgy 11.6 mgy	Corn stover, wheat straw, milo stub, switchgrass, and other biomass	The first phase of this project has been completed; a 1.5 metric ton/d biomass refinery pilot plant has been in operation since Sep 2007 in Kansas
AE Biofuels	Butte, MT	Small scale	Switchgrass, grass seed, grass straw, corn stalks	In Aug 2008, integrated starch cellulose ethanol plant opened
Bluefire	Irvine, CA Fulton, MS	18 mgy 3.1 mgy	Green waste, wood waste, and other cellulosic urban waste (postsorted municipal solid waste)	Dec 2009, Dept. of Energy increased the funding to $88 million for Phase II construction at Fulton, MS
California Ethanol +Power LLC	Brawley, CA	55 mgy	Local imperial valley grown sugarcane facility powered by sugarcane bagasse	Its initial project is expected to be in commercial operation in the 2nd quarter of 2012
Coskata	Madison, PA	40,000 gal/y	Any carbon-based feedstock, including biomass, municipal solid waste, bagasse, and other agricultural waste	‘‘Semicommercial facility’’ started Oct 2009; first commercial facility in design
Dupont Danisco Cellulosic Ethanol LLC	Vonore, TN	250,000 gal/y	Switchgrass, corn stover, corn fiber, corn cobs	The first demonstration plant in operation Dec 2009
Ecofin, LLC	Washington County, KY	1.3 mgy	Corn cobs	Project was canceled May 2009
Flambea River Biofuels LLC	Park Falls, WI	6 mgy	Softwood chips, wood, and forest residues	Planned operation by 2013
ICM Inc.	Shelley, ID	18 mgy	Agricultural residues including wheat straw, barley straw, corn stover, switchgrass, rice straw	First plant is expected to be operational before end of 2011
KL Process	Upton, WY	1.5 mgy	Softwood, waste wood including hardwood and softwood	Demonstration plant started production in 2008
Lignol Innovations/ Luncor	Grand Junction, CO	2.5 mgy	Woody biomass, agricultural residues, hardwood, and softwood	Completed industrial-scale pilot plant Jan 27, 2010
Mascoma/New York State Energy Research and Development Authority/ New York State Department of Agriculture and Markets	Rome, NY	5 mgy	Cellulosic biomass including switchgrass, paper sludge, and wood chips	Demonstration facility began producing cellulosic ethanol in Feb 2009
Mascoma/Michigan Economic Development corporation/Michigan State University/Michigan Technological University	Chippewa County, MI	40 mgy	Wood chips	Awaiting process performance and engineering data before continuing
New Page Corp. (formerly Store Enso North America)	Wisconsin Rapids, WI	5.5 mgy	Woody biomass, mill residues	Expected in-service date of late 2012
New Planet Energy (Formerly Alice)	Vero Beach, FL	first stage, 8 mgy; second stage, 21 mgy; third stage, 100 mgy	Municipal solid waste; unrecyclable paper; construction and demolition debris; tree, yard, and vegetative waste; and energy crops	Expected operation of phase one in 2012
Pacific Ethanol	Boardman, OR	2.7 mgy	Wheat straw, stover, and poplar residues	Still in early design and development phase; no production date yet scheduled
POET	Scotland, SD Emmetsburg, IA	20,000 gal/y 31.25 mgy	Corn fiber, corn cobs, and corn stalk	Scotland started in 2008; Emmetsburg under construction 2009–2011; Emmetsburg expected startup of biorefinery 2011
Range Fuels Inc.	Soperton, GA	20 mgy	Wood chips (mixed hardwood)	Production scheduled to commence in the second quarter of 2010
Verenium	Jennings, LA Highlands County, FL	1.4 mgy 36 mgy	Sugarcane bagasse, specially bred energy cane, high-fiber sugar cane	The first cellulosic ethanol pilot plant started in 2006 (Jennings); Highlands County plant expected to be in operation by 2012

[a] Sources: RFA 2010c and personal communication.

billion gallons and a reduction in corn price of 4.6 percent.

- Without ethanol tax credits, import tariffs, or mandates, average ethanol production would be reduced by 5.5 billion and corn prices would drop by 13.1 percent.
- Allowing 15 percent ethanol blends will increase ethanol use and corn prices; however this effect is limited because the demand for RFG fuel would not change substantially. Such a blend would expand the potential ethanol market and would likely increase corn price by 1.1 percent.

Cellulosic Ethanol

The Renewable Fuel Standard (EISA) that mandated using 16 billion gallons of cellulosic ethanol in the US automotive fuel supply by 2022 is currently the primary impetus for cellulosic ethanol production and growth. Beyond the advantages mandated by policy, cellulosic ethanol has technical advantages. In addition to being an oxygenator and raising octane levels, cellulosic ethanol lowers greenhouse gas and air pollutant emissions and has a favorable energy balance (Perez-Verdin et al. 2008, Yacobucci 2008a). Cellulosic ethanol is made from nonfood feedstocks, which unlike corn, do not compete with a food resource.

The Manufacture of Cellulosic Ethanol

Cellulosic ethanol is considered a major type of ''advanced'' biofuel and can be produced from a wide variety of cellulosic biomass feedstock, including agricultural plant residues (corn stover, cereal straw, and sugarcane bagasse), forest wastes (sawdust, wood chips, paper pulp, etc.), and ''energy'' crops such as switchgrass (Greer 2005).

Cellulosic ethanol and corn ethanol are chemically identical, but they are not equal in terms of environmental impact. According to a report by Argonne National Laboratory, based on indirect land use and carbon sink estimation, corn ethanol reduces greenhouse gas (GHG) emissions by 18 to 29 percent per vehicle mile traveled as compared with gasoline, while cellulosic ethanol decreases the GHG emissions by approximately 85 percent per vehicle mile traveled (Wang 2005).

The cellulose and hemicellulose components of forest and agricultural residues are essentially long, molecular chains of sugars. The major process being used for residue to ethanol conversion uses an enzyme to break down the long chain into fermentable sugar under certain pressures and temperatures. There are a number of technical obstacles in the conversion. Among them are the following (Anonymous 1999):

- The separation of lignin cellulosic material from the whole makes the remainder harder to hydrolyze.
- The hydrolysis of cellulose and hemicellulose takes place at different rates of reaction, and that can degrade the sugars into some materials that are not suitable for ethanol production.
- The hydrolysis produces a series of sugars. Not all of these sugars are fermentable with the standard yeast that is used in the corn ethanol industry.

Cellulosic Ethanol Costs

The estimated costs for producing cellulosic ethanol are elusive and, of necessity, change with time. Based on the current state of technology, capital costs for biochemical ethanol from cellulose are estimated to be between $5 and $5.60 per gallon of ethanol. These are the costs incurred for the purchase of land, buildings, construction, and equipment used in production. Operating costs are estimated to be between $1.34 and $1.69 per gallon depending on feedstock costs, enzyme cost, and the nature of the pretreatment (Newcomb 2009). Capital cost for future plants, which anticipate improvements in conversion technologies, are estimated to be $3.50 to $4.00 per gallon ethanol annual capacity. It is estimated that operating costs will drop to $0.40 to $0.89 per gallon of ethanol (Newcomb 2009).

Wright and Brown (2007) give a detailed comparison between a 150 million gallon per year cellulosic ethanol plant and a corn ethanol plant with the same scale. According to their analysis, corn ethanol presently has a big advantage over cellulosic ethanol with respect to total capital cost required for construction of a new plant. Their estimate for a corn ethanol plant is $111 million compared with a cellulosic plant at $756 million.

Manufacturing Initiatives

The rapidly expanding renewable fuels industry will soon have to turn their emphasis from corn ethanol to cellulosic ethanol because of the legal mandates described above. The Department of Energy has selected six cellulosic ethanol plants for up to $385 million in federal funding and 25 cellulosic ethanol plants are under construction (Tables 3 and 4; RFA 2010a, 2010b).

Summary

Although the comparative costs for corn versus cellulosic ethanol favor corn, there are potential benefits from the development of cellulosic ethanol including oxygenation and octane increases, lower greenhouse gas and air pollutant emissions, and a favorable energy balance. Furthermore, cellulosic ethanol production would allow for the production of liquid biofuels using nonfood feedstocks. Given the current state of technology, there is no clear advantage in capital or operating costs for the production of cellulosic ethanol compared with corn ethanol. However, considering the extra benefit from federal and state cellulosic ethanol policies, cellulosic ethanol can still compete with corn ethanol, especially if the price of corn increases, the high capital costs of cellulosic ethanol plants drop, and the full range of benefits for cellulosic ethanol production are considered.

Literature Cited

Alternative Fuels and Advanced Vehicles Data Center (AFDC). 2008. U.S. consumption of ethanol and MTBE oxygenates. US Department of Energy, Washington, D.C. www.afdc.energy.gov/afdc/data/fuels.html. Accessed March 18, 2009.

American Coalition for Ethanol. 2010. Federal legislation. Sioux Falls, South Dakota. http://www.ethanol.org/index.php?id=78&parentid=26#Volumetric%20Ethanol%20Excise%20Tax%20Credit. Accessed March 19, 2010.

Anonymous. 1999. Wood-ethanol report. http://www.journeytoforever.org/biofuel_library/WoodEthanolReport.html. Accessed March 19, 2010.

Energy Information Administration (EIA). 2007. Annual energy outlook 2007 with projections to 2030. DOE/EIA-0383(2007). EIA, Office of Integrated Analysis and Forecasting, US Department of Energy, Washington, D.C. 243 pp.

Energy Information Administration (EIA) 2008. Annual energy outlook 2008 with projections to 2030. DOE/EIA-0383(2008). EIA, Office of

Integrated Analysis and Forecasting, US Department of Energy, Washington, D.C. 224 pp.
Energy Information Administration (EIA) 2009. Annual energy outlook 2009 with projections to 2030. DOE/EIA-0383(2009). EIA, Office of Integrated Analysis and Forecasting, US Department of Energy, Washington, D.C. 230 pp.
Energy Information Administration (EIA) 2010. Status and impact of state MTBE ban. EIA, US Department of Energy, Washington, D.C. http://www.eia.doe.gov/oiaf/servicerpt/mtbeban/. Accessed March 19, 2010.
Greer, D. 2005. Creating cellulosic ethanol: Spinning straw into fuel. *BioCycle* 46:61–65.
Gross, P. 2007. Biofuels in the U.S. transportation sector. *In:* Issues in Focus, Annual Energy Outlook 2007. http://www.eia.doe.gov/oiaf/aeo/otheranalysis/bts.html. Accessed March 19, 2010.
Koplow, D. 2007. Biofuels—At what cost? Government Support for Ethanol and Biodiesel in the United States. Global Subsidies Initiative of the International Institute for Sustainable Development, Geneva. 8 pp.
Kovarik, B. 1998. Henry Ford, Charles F. Kettering and the fuel of the future. *Automotive Hist. Rev*. Spring(32):7–27.
Lidderdale, T. 2003. Motor gasoline outlook and state MTBE bans. Energy Information Administration, Department of Energy, Washington, D.C. www.eia.doe.gov/emeu/steo/pub/special/mtbeban.html. Accessed March 19, 2010.
Meyer, S. 2009. Impacts of selected US ethanol policy options. FAPRI-MU Report 04-09. Food and Agricultural Policy Research Institute, University of Missouri, Columbia. 51 pp.
Newcomb, J. 2009. U.S. economic impact of advanced biofuels production: Perspectives to 2030. Bio Economic Research Associates, Cambridge, Massachusetts. 29 pp.
Perez-Verdin, G., D. L. Grebner, I. A. Munn, C. Sun, and S. C. Grado. 2008. Economic impacts of woody biomass utilization for bioenergy in Mississippi. *Forest Prod. J*. 58(11):75–83.
Renewable Fuels Association (RFA). 2010a. Ethanol industry statistics. RFA, Washington, D.C. http://www.ethanolrfa.org/pages/statistics. Accessed May 14, 2010.
Renewable Fuels Association (RFA). 2010b. Annual industry outlook 2010. RFA, Washington, D.C. http://www.ethanolrfa.org/pages/annual-industry-outlook. Accessed May 14, 2010.
Renewable Fuels Association (RFA). 2010c. U.S. advanced and cellulosic ethanol projects under development and construction. RFA, Washington, D.C. http://www.ethanolrfa.org/page/-/rfa-association-site/Outlook/CurrentAdvancedCelluloseBiofuelsProjects2-25-10.pdf?nocdn=1. Accessed May 14, 2010.
Tyner, W. 2007. U.S. ethanol policy—Possibilities for the future. Purdue Extension ID-342-W. Department of Agricultural Economics, Purdue University, West Lafayette, Indiana. 8 pp.
US Environmental Protection Agency (EPA). 2007. State actions banning MTBE. EPA420-B-07-013. Office of Transportation and Air Quality, EPA, Washington, D.C. 4 pp.
US Environmental Protection Agency (EPA). 2010. Methyl tertiary butyl ether (MTBE). EPA, Washington, D.C. http://www.epa.gov/mtbe/gas.htm. Accessed March 30, 2010.
Wang, M. 2005. The debate on energy and greenhouse gas emissions impacts of fuel ethanol. *In:* Energy Systems Division Seminar, August 3, 2005, Argonne National Laboratory; Argonne National Laboratory, University of Chicago, Argonne, Illinois. 35 pp.
Wright, M. M. and R. C. Brown. 2007. Comparative economics of biorefineries based on the biochemical and thermochemical platforms. *Biofuels Bioprod. Biorefining* 1:49–56. DOI:10.1002/bbb.
Yacobucci, B. D. 2008a. Fuel ethanol: Background and public policy issues. CRS Report for Congress, Order Code RL33290, April 24. Congressional Research Service, Library of Congress, Washington, D.C. 27 pp.
Yacobucci, B. D. 2008b. Ethanol imports and the Caribbean basin initiative. CRS Report for Congress, Order Code RS21930, March 18. Congressional Research Service, Library of Congress, Washington, D.C. 6 pp.