The U.S. Ethanol Industry

Mark D. Stowers

Ethanol is vital to achieving greater American energy independence. It is today's only viable and available fuel that can be substituted for gasoline. Unlike oil, ethanol is renewable—it will never run out. As science moves from making ethanol from corn to producing it from corn cobs and other plant materials, ethanol will continue to be a sustainable and effective energy solution for the world. America's dependence on foreign oil causes enormous problems for Americans every day—raising the prices on everything from gas to groceries and sending money and jobs overseas. This article summarizes the state of the ethanol industry. (JEL Q20, Q21, Q28, Q40, Q42)

Federal Reserve Bank of St. Louis *Regional Economic Development*, 2009, *5*(1), pp. 3-11.

POET, headquartered in Sioux Falls, South Dakota, is the largest ethanol producer in the world. POET is an established leader in the biorefining industry through project development, design and construction, research and development, plant management, ownership, and product marketing. The 20-year-old company has built 32 ethanol production facilities and currently manages 26 plants in the United States while marketing more than 1.5 billion gallons of ethanol and 4 million tons of distillers' grains annually.

Since 2000, POET has constructed 21 greenfield ethanol plants in seven states and completed six major expansions of existing facilities. The value of POET's design-build contracts since 2000 has exceeded $1 billion. Each project has been successfully designed, built, and managed by POET. These projects have resulted in the addition of more than one billion gallons of new fuel ethanol capacity per year.

The POET development model is unique. It started on the Broin family farm in Minnesota and has spurred the growth of investment by thousands of farmers and individual Main Street investors. POET's business model is to invest in, develop, design, construct, and manage ethanol production facilities. However, the facilities are independent limited liability companies (LLCs) owned by POET, individuals, and local farmers that provide the corn feedstock. POET employs the general manager and on-site technical engineer at each facility. All other employees are employed by the LLC. POET also has representation on the board of directors at each plant.

By leveraging business size and position, POET has created the most successful ethanol facilities in the industry. POET has achieved breakthrough progress beyond ethanol processing, extracting extraordinary new value from each kernel of corn.

ETHANOL INDUSTRY BACKGROUND

The ethanol industry now produces more than 10 billion gallons of fuel ethanol, representing 7 percent of the gasoline supply, and 70 percent of all gasoline sold contains some ethanol. Ethanol contributes more than $45 billion to the U.S. gross

Mark D. Stowers is vice president of research and development at POET.

domestic product annually, has created more than 238,000 jobs, and has contributed $12 billion to consumers through lower transportation fuel prices. During 2007, 6.5 billion gallons of domestically produced ethanol displaced 228 million barrels of imported oil (Renewable Fuels Association [RFA], 2008a). As of February 1, 2009, 180 ethanol plants have been constructed with a production capacity of 12.2 billion gallons with an additional 1.5 billion gallons of capacity under construction. About 1.9 billion gallons of capacity is currently idled due to poor market conditions (RFA, 2008b).

ETHANOL BENEFITS

Ethanol has the highest octane rating of any fuel and keeps today's high-compression engines running smoothly. E10 (which is 90 percent gasoline and 10 percent ethanol) is a cleaner-burning fuel than straight gasoline. Ethanol-blended fuels do not leave gummy deposits on the fuel system and prevent wintertime problems by acting as gasline antifreeze. Since the 1980s, all automaker warranties have allowed the use of E10. Ethanol has been criticized for having fewer British thermal units (BTUs) per gallon than gasoline. However, ethanol's combustion efficiency compensates for some of its lower energy content. Ethanol's 113 to 115 octane rating compared with unleaded gasoline's 87 allows high-compression engines to perform just as well on fewer BTUs. The ethanol blends used today (E10 and E30) have little impact on fuel economy or vehicle performance.

Using ethanol as a vehicle fuel provides local and global benefits: It reduces emissions of harmful pollutants and greenhouse gases (GHGs). Ethanol is the only currently available solution for reducing GHG emissions from the current fleet of vehicles. Ethanol results in fewer GHG emissions than gasoline and is fully biodegradable, unlike some fuel additives. Production of ethanol requires one-third less fossil-fuel energy than gasoline, reducing GHG emissions. The higher the amount of ethanol blended with gasoline, the lower the GHG emissions. In 2007, ethanol use in the United States reduced carbon dioxide (CO_2)–equivalent GHG emissions by approximately 10.1 million tons, which is equal to removing more than 1.5 million cars from America's roadways (Wang, 2007).

Life-cycle analysis compares CO_2 emissions produced during the entire process of ethanol and gasoline production (field to wheels and wells to wheels, respectively). For ethanol these steps include growing the feedstock crops, transporting them to a production plant, producing the ethanol, distributing it, and burning it in vehicles. For gasoline these include extracting crude oil from the ground, transporting it to a refinery, refining the crude oil into gasoline, distributing the gasoline, and burning it in vehicles. Studies have shown that, when these entire life cycles are considered, using corn-based ethanol instead of gasoline reduces GHG emissions by 49 to 58 percent, depending on the source of energy for ethanol production (Liska et al., 2009).

ETHANOL PRODUCTION EFFICIENCY

Ethanol production efficiency has increased dramatically since the late 1980s when corn starch required cooking, enzymes inefficiently converted starch to sugars, and fermentation ethanol titers were 10 percent. Recently, the Argonne National Laboratory compared ethanol plants built in 2006 and 2001. Results showed a 6.4 percent increase in ethanol yields, 21.8 percent reduction in energy use, and 26.6 percent decrease in water consumption with the newer plants (Wang, 2007). Today POET ethanol plants produce ethanol at titers of 20 percent without cooking the starch and with enzymes that efficiently process starch for pennies per gallon of ethanol produced.

MID-LEVEL ETHANOL BLENDS

With the Energy Independence and Security Act of 2007 the U.S. government mandated a gradual increase in the country's use of renewable fuels such as ethanol until 2022, when the mandate reaches 36 billion gallons. However, because current government regulation restricts the ethanol blend to E10, ethanol producers will hit a regulatory cap—although they can produce enough ethanol to displace more than 10 percent of the fuel supply, no more than 10 percent may be used. Ethanol producers expect to hit this regulatory cap in 2009.

Multiple comprehensive studies have evaluated the effects of ethanol-gasoline blends above 10 percent ethanol, including, specifically, E15 and blends as high as E85. These studies involved over 100 vehicles, 85 vehicle and engine types, and 33 fuel-dispensing pumps and included a yearlong drivability test and over 5,500 hours of materials compatibility testing. One such study, West et al. (2008), a peer-reviewed report by the Oak Ridge National Laboratory for the Department of Energy (DOE), studied the effects of E15 and E20 on motor vehicles and small nonroad engines. This study compared E15 and E20 with traditional gasoline and concluded there were no significant changes in vehicle tailpipe emissions, vehicle drivability, or small nonroad engine emissions with either ethanol blend.

ETHANOL AND GOVERNMENT POLICY

Government support for ethanol levels the playing field in the heavily subsidized energy sector and is designed to reduce U.S. dependence on foreign oil, improve the environment, and foster rural development.

The Volumetric Ethanol Excise Tax Credit (VEETC) or "blenders' credit" was created as part of the American Jobs Creation Act of 2004. VEETC provides oil companies with an economic incentive to blend ethanol with gasoline. The tax credit totals 51 cents per gallon of pure ethanol; for example, 5.1 cents per gallon for ethanol in E10 (10 percent ethanol in gasoline). The VEETC provides market access for ethanol and provides significant benefits to U.S. taxpayers. In 2007 the blenders' credits totaled approximately $3.3 million. In the same year, the ethanol industry contributed $47.6 billion to the nation's gross domestic product, created more than 200,000 jobs, and generated an estimated $4.6 billion in tax revenue for the federal government. In addition, because of higher prices for agricultural commodities, expected direct-support payments to farmers (as provided through the Farm Bill) was approximately $8 billion less than expected (Urbanchuk, 2008). The VEETC is currently authorized through December 31, 2010.

U.S. ethanol imports are subject to a 2.5 percent ad valorem tariff, which is quite modest compared with the tariffs that other countries impose. For example, Brazil levies a 20 percent ad valorem tariff on ethanol imports. All ethanol blended with gasoline in the United States qualifies for the blenders' credit, regardless of the country of origin of the ethanol. To offset this and ensure that taxpayer dollars do not support foreign ethanol production, U.S. ethanol imports from non-Caribbean Basin countries are subject to a 54 cent per gallon secondary tariff. This tariff is in effect through December 31, 2010.

If the secondary tariff on ethanol imports were to be eliminated, ethanol imports would jeopardize the domestic ethanol industry that is already keeping gas prices lower. Many ethanol critics have suggested that the tariff should be discontinued. The removal of the secondary tariff would be harmful to the corn-based ethanol industry and also have a devastating impact on the developing cellulosic ethanol industry in that investors would likely not fund further infrastructure development. It is critical for the cellulosic ethanol industry to have a market opportunity while it is in its earliest development stages. If the United States were to subsidize foreign ethanol, it would significantly diminish the promise of cellulosic ethanol.

The Renewable Fuel Standard (RFS) was part of the Energy Independence and Security Act of 2007 and sets annual requirements for the amount of renewable fuels produced and used in motor vehicles. Under the bill, the RFS required 9 billion gallons of renewable fuels in 2008 and progressively increases to 36 billion gallons by 2022. Further, the bill requires advanced biofuels, such as cellulosic ethanol, to become an increasing portion of renewable fuels: from 3 billion gallons in 2016 to 21 billion gallons in 2022.

The RFS is important to the ethanol industry because ethanol is the only available near-term solution to two of our country's most pressing challenges: energy security and global warming.

Despite the obvious benefits, the RFS is needed to ensure that ethanol has market access. Without the RFS, it is highly unlikely that biofuels would ever be much more than a blending agent because oil companies would rather use their own product.

The RFS also helps to ensure a market for cellulosic ethanol. It calls for two-thirds of renewable fuels to be from advanced biofuels like cellulosic ethanol by 2010. Cellulosic ethanol already has a steep hill to climb to be commercially viable. Without an ensured market, it would be even more difficult.

MEETING A SIGNIFICANT AMOUNT OF DEMAND THROUGH CORN ETHANOL

Corn has been the predominant feedstock for the production of ethanol, and its main advantages are that (i) its abundance and oversupply result in lower costs for food, feed and, fuel products; (ii) starch, which is the major component of the corn kernel, is relatively easy to process; and (iii) the infrastructure for corn distribution is well established.

Seed companies' ability to continually improve corn yields represents the most important factor for corn's long-term viability as an ethanol feedstock. Based on the current corn yield of 150 bushels an acre (bu/acre) and historical trends for corn yield growth, projected corn yields are 180 bu/acre in 2022 and 200 bu/acre in 2030. Monsanto, for example, projects corn yields of 210 to 250 bu/acre by 2022 and 265 to 300 bu/acre by 2030 (Begemann, 2008). Using 300 bu/acre and the current 86.5 million U.S. corn acres, the projected annual corn production level for 2030 would exceed 26 billion bushels—double the 2007 corn production. If corn demand for food and feed in 2030 were to increase by 40 percent from the 2007 level, there would be enough corn to meet this demand *and* increase corn ethanol production by over 425 percent from the 2007 level—to 48.6 billion gallons (assuming a 6.9 percent increase in ethanol-processing efficiency by then).

COMMITMENT TO CELLULOSIC ETHANOL

According to a recent U.S. Department of Commerce International Trade Administration Study, "Energy in 2020: Assessing the Economic Effects of Commercialization of Cellulosic Ethanol" (Osborne, 2007), by 2020 there will be enough cellulosic feedstock available in the United States to produce nearly 50 billion gallons of cellulosic ethanol. At this production rate, over 1.2 million barrels per day of crude oil could be displaced while creating over 54,000 jobs in U.S. agriculture. In more practical terms, at this level of ethanol production the United States could eliminate all oil purchases from the Organization of the Petroleum Exporting Countries (OPEC) and the Middle East—eliminating the daily export of 1.4 billion U.S. dollars to overseas oil producers (based on oil priced at $120 per barrel).

Along with economic benefits, cellulosic ethanol offers significant environmental benefits. Each gallon of gasoline produces 25 pounds of CO_2-equivalent GHG emissions. By comparison, cellulosic ethanol reduces GHG emissions by a little more than 21 pounds of CO_2 per gallon—that's an 85 percent reduction. To monetize that benefit we can assign a value of $20 per ton of CO_2-equivalent GHG emissions based on current European futures prices for CO_2 equivalents. Accordingly, the use of a little more than 20 billion gallons of cellulosic ethanol would reduce the cost of GHG emissions by about 19 cents per gallon, or about $2.5 billion per year. Cellulosic ethanol's value to the U.S. economy, the environment, and national security is substantial. At POET we believe that cellulosic ethanol is real and achievable.

POET's commitment to cellulosic ethanol started eight years ago when our company developed proprietary fractionation and raw starch hydrolysis technologies. Specifically, these technologies allow POET to process corn starch more efficiently and economically. Our proprietary corn fractionation technology, or BFrac as it is referred to in the industry, allows the separation of the corn starch from the corn germ and corn fiber, the cellulosic casing that protects the corn kernel.

Another proprietary process called Broin Project X (BPX) processes the starch without cooking, resulting in (i) an 8 to 12 percent reduction in BTU consumption, (ii) greater conversion of corn starch to ethanol, and (iii) a high-nutrient density animal feed product, which we call Dakota Gold. This technology uses less fossil fuel than previous processes, yields more ethanol per acre of corn, and provides an animal feed product that can replace corn. The corn germ can be processed to produce crude or refined corn oil, which has multiple end uses ranging from cooking to biodiesel. The corn fiber, due to its high sugar content, can be processed to ethanol.

Important points to note about corn ethanol production plants are that they are (i) highly efficient, (ii) actually produce more than just ethanol, and (iii) serve as sources for cellulosic feedstocks.

POET began its efforts to develop cellulosic ethanol technology in 2002 with one of the first biorefinery grants from the DOE. The effort focused on what was termed then a "second-generation dry mill biorefinery," which sought to incorporate corn fractionation into a dry mill ethanol plant, processing the cellulosic corn fiber into ethanol and producing a higher-protein animal feed product. Quite honestly, this effort produced mixed results. POET was able to incorporate a corn fractionation system into a dry mill ethanol plant and to produce a higher-protein animal feed product, but the ability to process corn fiber to ethanol proved more difficult because of limited ability to break down the corn fiber into usable sugars and the lack of known microorganisms to ferment sugar into ethanol.

In 2006 a new strategy for cellulosic ethanol production was developed. The strategy uses existing corn ethanol plants to (i) capitalize on existing infrastructure (utilities, roads, rail lines, materials handling, and so forth); (ii) focus on corn cobs as the primary cellulosic feedstock to use the existing farmer (and often investor) network to collect cobs; and (iii) eliminate the use of fossil fuels by processing waste streams (that is, by-products of the cellulose-to-ethanol process) to generate energy for the entire plant. This "bolt-on" approach is designed to use the expansive ethanol base to enable rapid adoption of the cellulosic ethanol process. POET is implementing this strategy through Project LIBERTY, which is the creation of an integrated corn cellulose biorefinery.

Project LIBERTY will transform the POET biorefinery in Emmetsburg, Iowa, from a conventional corn dry mill ethanol plant into an integrated corn-to-ethanol and cellulose-to-ethanol biorefinery. Once complete the facility will produce 125 million gallons of ethanol per year, 25 of which will come from a feedstock of corn fiber and corn cobs. Also, the facility will produce 80,000 tons of Dakota Gold Corn Germ Dehydrated and 100,000 tons of Dakota Gold HP animal feeds annually. Project LIBERTY will produce 11 percent more ethanol from a bushel of corn through the corn fractionation process and 27 percent more ethanol from an acre of corn through the use of corn cobs. In addition, Project LIBERTY will reduce the biorefinery's need for fossil fuels by nearly 100 percent. The total cost of the project will exceed $200 million. It will create at least 30 new jobs at the facility, but more importantly, Project LIBERTY will demonstrate the profitability of cellulosic ethanol technology on a replicable commercial scale. POET's longer-term plans are to roll out this technology suite to other existing dry mills or new grassroots biorefineries. As partners with POET in Project LIBERTY, the DOE and the Iowa Power Fund will contribute up to 50 percent or $100 million in project costs. Project LIBERTY is expected to be operational in late 2011.

Cellulosic feedstocks can be agricultural residues such as corn cobs, rice straw, or corn stover (leaves, stalks, and cobs left in the fields after harvest). They can also be wood fibers such as forestry wastes or wood wastes or energy crops such as switchgrass or Miscanthus grass. Cellulosic feedstocks could also be collected from municipal waste. POET has selected corn cobs as the first cellulosic feedstock for the production of cellulosic ethanol because they offer significant technical, environmental, and economic advantages. They are typically left in the field as corn stover after the harvest of the corn kernels and are easy to separate because they are heavier than the stalk. They are rich in sugars yet can be removed from the field with little environmental impact because they offer little value as fertilizer. And they can be collected relatively easily by the same farmers who provide the corn grain to the ethanol plant.

Through work with collaborators and in particular the enzyme companies, POET continually improves the cellulosic ethanol process. Recent work at POET resulted in a process to break down corn cobs into simple sugars, resulting in a 60 percent increase in the yield of ethanol from cobs compared with just a few months earlier. With this process, corn-cob feedstocks are more easily digested by enzymes without creating toxic by-products, which results in significant amounts of sugars for fermentation to ethanol.

Significant progress has been made in producing ethanol from simple sugars through the discovery of better microorganisms and a better fermentation process. And, lastly, through POET's cutting-edge process engineering expertise, we have devised a synergistic concept that enables a conventional corn ethanol plant to transition into one that uses only cellulosic feedstock. Although these are important breakthroughs, further process improvements over the next few months are needed to make the process profitable.

ALTERNATIVE ENERGY AND CELLULOSIC ETHANOL

Alternative energy plays an important role in the cellulosic ethanol process. Because of the low nutritional value of cellulosic ethanol waste streams (the by-products of ethanol production), they cannot be used as animal feed products. The most favorable use of these streams is feedstock for solid-fuel boilers or anaerobic digestion.

POET is currently installing a solid-fuel boiler at its biorefinery in Chancellor, South Dakota, which will process up to 500 tons of dried wood chips from a waste pallet processor to produce steam for the plant. This biorefinery has also reached an agreement with the city of Sioux Falls to purchase landfill gas for the boiler. By using wood and landfill gas, 67 percent of the energy needs at the Chancellor plant can be met, decreasing the need for fossil fuels by the same amount.

POET's Project LIBERTY will also incorporate a solid-fuel boiler in its design. The feedstock for the LIBERTY boiler will be solid wastes from the cellulosic ethanol operation and additional corn cobs collected as part of the cellulosic feedstock. When coupled to an anaerobic digestion system to process the liquid wastes from the cellulosic operation, the boiler will supply nearly all of the energy needs for the cellulosic- and starch-based operations.

CRITICAL SUCCESS FACTORS FOR WIDESPREAD USE OF ETHANOL

The continued development and commercialization of cellulosic ethanol underscores the importance of the following[1]:

1. **The Existing Corn-to-Ethanol Business and Infrastructure.** Without a viable corn-to-ethanol industry, cellulosic ethanol will be delayed. The corn-to-ethanol industry can provide an existing network of corn growers; production knowledge; and product, market, and logistics knowledge to emerging cellulosic ethanol producers.
2. **The Renewable Fuel Standard.** The RFS provides an important target for cellulosic ethanol—a real and attainable target. Continued support of the RFS will demonstrate to the ethanol, transportation fuel, and financial industries that there will be a market for ethanol.
3. **Increased Usage of Ethanol and Greater Numbers of Flexible-Fuel Vehicles.** Recent important research (see Appendix B) supports greater concentrations of ethanol to replace gasoline—expanding the use of ethanol beyond its historical role as a fuel oxygenate. So called "mid-level blends" (those greater than E15) of liquid transportation fuels have shown no deleterious impact on vehicles in the current U.S. automotive fleet. These mid-level blends will further reduce our dependence on foreign oil, reduce our fuel costs, and help the environment.
4. **Governmental Support.** Governmental programs are necessary, especially during the

[1] For further study of the ethanol industry, see the resources noted in Appendix A.

early stages of the cellulosic ethanol industry's development, to enable financing at the grower/farmer level and to offer cellulosic ethanol producers incentives, loan guarantees, and market assurances. The maintenance of the VEETC and import tariffs on ethanol remain important so long as ethanol use in the liquid transportation fuels remains low and the purchasing power of oil refiners remains high.

5. **Continued Investment in Research and Development.** Significant cost reductions in the cellulosic ethanol process are required. The cost of enzymes still remains one of the most significant variable costs associated with the process.

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Urbanchuk, John M. "Economic Contribution of the Partial Exemption for Ethanol from the Federal Excise Tax on Motor Fuel: Increased Revenues and Reduced Dependence on Foreign Oil." LECG, 2008; www.lecg.com/files/Publication/e3c2b607-e4b1-4be3-96c7-99360d2b9993/Presentation/PublicationAttachment/cf3c9c9e-9580-4e52-add9-9b878810e4d3/exisetax.pdf.

Wang, Michael. "Analysis of the Efficiency of the U.S. Ethanol Industry 2007." Presented to the Renewable Fuels Association, March 27, 2008; /www1.eere.energy.gov/biomass/pdfs/anl_ethanol_analysis_2007.pdf.

West, Brian; Knoll, Keith; Clark, Wendy; Graves, Ronald; Orban, John; Przesmitzki, Steve and Theiss, Timothy. "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1." NREL/TP-540-43543; ORNL/TM-2008/117. National Renewable Energy Laboratory, October 2008; http://feerc.ornl.gov/publications/Int_blends_Rpt_1.pdf.

APPENDIX A

Additional Reading

Argonne National Laboratory, Energy Systems Division. "Life-Cycle Assessment of Energy and Greenhouse Gas Effects of Soybean-Derived Biodiesel and Renewable Fuels." March 12, 2008; www.transportation.anl.gov/pdfs/AF/467.pdf.

Dale, Bruce. "Thinking Clearly about Biofuels, Bioproducts and Biorefining." *SCITIZEN*, August 15, 2007; www.scitizen.com/stories/Future-Energies/2007/08/Thinking-Clearly-about-Biofuels-Ending-the-Irrelevant—Net-Energy—Controversy/.

U.S. Department of Energy. "Ethanol Myths Under the Microscope." 2007; www1.eere.energy.gov/biomass/pdfs/ethanolmyths2007.pdf.

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. "Ethanol: The Complete Energy Lifecycle Picture." March 2007; www1.eere.energy.gov/vehiclesandfuels/pdfs/program/ethanol_brochure_color.pdf.

U.S. Department of Energy. "Fact Sheet: Gas Prices and Oil Consumption Would Increase Without Biofuels." June 11, 2008; www.energy.gov/media/FactSheet__Biofuels_Lower_Gas_Prices.pdf.

U.S. Department of Energy. "Ethanol Greenhouse Gas Emissions." February 4, 2009 update; www.eere.energy.gov/afdc/ethanol/emissions.html.

Whitten, Gary. "Air Quality and Ethanol in Gasoline." Presented at the 9th Annual National Ethanol Conference *Policy & Marketing*, February 16-18, 2004; www.oregon.gov/ENERGY/RENEW/Biomass/docs/FORUM/Whitten2004.pdf.

APPENDIX B

Summary of Research Findings on Higher Ethanol Blends

Bonnema, Grant; Guse, Gregory; Senecal, Neil; Gupta, Rahul; Jones, Bruce and Ready, Kirk L. "Use of Mid-Range Ethanol/Gasoline Blends in Unmodified Passenger Cars and Light Duty Trucks." Minnesota Center for Automotive Research, July 1999; www.ethanol.org/pdf/contentmgmt/E30_Final_Report.pdf.

This one-year study evaluated the effects of E10 and E30 in 15 older vehicles in "real world" driving conditions and found that regulated exhaust emissions from both fuels were well below federal standards.

Egebäck, Karl-Erik; Henke, Magnus; Rehnlund, Björn; Wallin, Mats and Westerholm, Roger. "Blending of Ethanol in Gasoline for Spark Ignition Engines: Problem Inventory and Evaporative Measurements." Report No. MTC 5407, AVL MTC Tech Centre, Haninge, Sweden, 2005.

Researchers tested and compared evaporative emissions from E0, E5, E10, and E15 and found lower total hydrocarbon emissions and lower evaporative emissions from E15 than from E10 and E5. Specifically,

(i) no significant difference can be seen in regulated emissions when comparing the use of blended fuel (with up to 10 to 15 percent ethanol) with the use of neat gasoline, and
(ii) due to the gasoline dilution effect of adding ethanol, the emissions of benzene, toluene, ethylbenzene, and xylene blended with ethanol are lower than those from neat gasoline, which offers health and environmental benefits.

Haskew, Harold M.; Liberty, Thomas F. and McClement, Dennis. "Fuel Permeation from Automotive Systems: E0, E6, E10, E20 and E85." CRC Report No. E-65-3, Coordinating Research Council, Inc., December 2006; www.crcao.com/reports/recentstudies2006/E-65-3/CRC%20E-65-3%20Final%20Report.pdf.

Researchers evaluated the effects of E0, E6, E20, and E85 on the evaporative emissions rates from permeation in five newer California vehicles and found there was no statistically significant increase in diurnal permeation rates between E6 and E20.

Knoll, Keith; West, Brian; Clark, Wendy; Graves, Ronald; Orban, John; Przesmitzki, Steve and Theiss, Timothy. "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1." NREL/TP-540-43543; ORNL/TM-2008/117. National Renewable Energy Laboratory of the Oak Ridge National Laboratory for the U.S. Department of Energy, October 2008; http://feerc.ornl.gov/publications/Int_blends_Rpt_1.pdf.

This peer-reviewed study regarding the effects of E15 and E20 on motor vehicles and small nonroad engines concluded that compared with traditional gasoline neither E15 or E20 has significant changes in vehicle tailpipe emissions. The findings include the following:
(i) Regulated tailpipe emissions remained largely unaffected by the ethanol content of the fuel.
(ii) As ethanol content increased, oxides of nitrogen and nonmethane organic gases showed no significant change.
(iii) Nonmethane hydrocarbons and CO_2 emissions dropped slightly on average, although CO_2 did not change appreciably from E10 to E20.

Shockey, Richard E. and Aulich, Ted R. "Optimal Ethanol Blend-Level Investigation, Final Report." Energy and Environmental Research Center and Minnesota Center for Automotive Research for the American Coalition for Ethanol, October 2007;
www.ethanol.org/pdf/contentmgmt/ACE_Optimal_Ethanol_Blend_Level_Study_final_12507.pdf.

Researchers studied the effects of ethanol blends ranging from E10 to E85 on motor vehicles and found that exhaust emissions levels for all vehicles at all ethanol blends tested were within the applicable Clean Air Act standards.