Ethanol Basics

Ethanol is an alternative fuel made from a variety of plant-based feedstocks collectively known as "biomass." It is typically blended up to 10% with gasoline (E10) for use in conventional vehicles to meet state renewable fuel mandates and to reduce air pollution. Ethanol is also increasingly available in blends of 85% ethanol, 15% gasoline. Known as E85, it can be used in the more than six million flexible fuel vehicles (FFVs) driving on U.S. roadways today. Studies estimate that ethanol and other biofuels could replace more than 30% of gasoline demand in the United States by 2030.

Fuel ethanol contains the same chemical compound as beverage alcohol, but it is "denatured," or made unpotable with a small amount of gasoline (or other denaturant), during the production process, so it is unsafe for human consumption. Like beverage alcohol, it is currently made by fermenting sugars derived from starch crops such as corn or found in plants like sugar cane. Ethanol can also be made from cellulosic materials, such as grass, wood, crop residues, or newspapers. However, this process is more technically challenging because these materials must first be broken down into component sugars. The first commercial plants for producing cellulosic ethanol are now being built.

Production

How is corn ethanol produced?

Corn ethanol is produced in two ways: wet milling and dry milling. The primary difference between these processes is in the initial grain treatment. During dry milling, the entire corn kernel is ground into a powder, mixed with water to form a mash, then cooked with added enzymes that turn the starch into glucose, a sugar. For wet milling, the grain is soaked or "steeped" in hot water, a process that facilitates the separation of the grain into its component parts.

Only the starch in grains is used to make ethanol. The remaining nutrients—protein, fiber, and oil—are used to create by-products. Wet mills produce corn oil and gluten meal, high fructose corn syrup, and starch, while dry mills produce dried distillers grains with solubles (DDGS), which are used as a livestock feed. Carbon dioxide is also a by-product of ethanol production that is sometimes captured and processed into a commercial-grade liquefied form.

What is cellulosic ethanol, and when will it be available?

Cellulosic ethanol is made from the woody or structural parts of plants. Examples of these materials include agricultural residues, such as corn stover, cereal straws, and sugarcane bagasse; industrial waste, such as sawdust and paper pulp; forestry residues, such as small trees and excess wood; and energy crops, such as switchgrass, hybrid poplars, and willows, specifically grown for fuel production. The cell walls of these materials are comprised of long sugar chains (carbohydrates). The sugar in these cell walls is extracted through the introduction of enzymes or acids, and then converted to ethanol using micro-organisms. Due to the complex structure of the cell walls, it is more difficult to break cellulosic materials into sugar, making them more expensive to convert to ethanol. Even with its complexity, cellulosic ethanol holds the promise of reducing petroleum use and lifecycle greenhouse gases (GHGs), and, because it is made from non-food crops, cellulosic ethanol should not affect the food supply and should likely reduce impact on land and water.

Developing processes to economically break down cellulosic feedstock components is the focus of research now being conducted by the U.S. Department of Energy (DOE) and other government and industry groups. Studies are examining biochemical processes that use microorganisms and thermochemical methods (heat) to convert the cellulosic feedstocks into fuel.[1]

Cellulosic ethanol is not yet readily available; however, several commercial cellulosic ethanol production plants are in development. In 2007, DOE announced a multimillion dollar investment to build several cellulosic ethanol biorefineries to advance the commercial production of this and other biofuels.

[1] NREL. "Biomass Economy: Biorefineries." 2006 Research Review. www.nrel.gov/research_review/pdfs/2002/31967b.pdf.

Vehicle Applications

What are the different ethanol blends, and can they be used in any vehicle?

Nearly half of U.S. gasoline contains up to 10% ethanol. The U.S. Environmental Protection Agency (EPA) classifies low-level ethanol blends (up to E10) as "substantially similar" to gasoline, meaning that they can be used legally in any gasoline-powered vehicle without modification.

E85 is considered an alternative fuel under the Energy Policy Act of 1992. It can be used in E85-capable FFVs, which are available in a variety of models produced by domestic and foreign automakers. As of August 2008, E85 is available at 1,528 fuel stations in 43 states.[2]

Intermediate ethanol blends, which are composed of more than 10% and less than 85% ethanol, are becoming available in limited areas. These blends can only be used in FFVs.

How do FFVs differ from conventional vehicles?

There are several differences between FFVs and gasoline-powered vehicles. The fuel-system components are made of ethanol-compatible materials, and the control-system elements are modified to handle the variable combustion characteristics of the various gasoline/ethanol mixtures that can be used in FFVs. Figure 1 shows the specialized components of an FFV.

Can I convert my car to run on E85?

Converting a conventional gasoline vehicle to run on E85 is technically possible. But to legally do so, only conversions that have an EPA Certificate of Conformity can be performed. In California, conversions must also be certified by the California Air Resources Board (CARB).

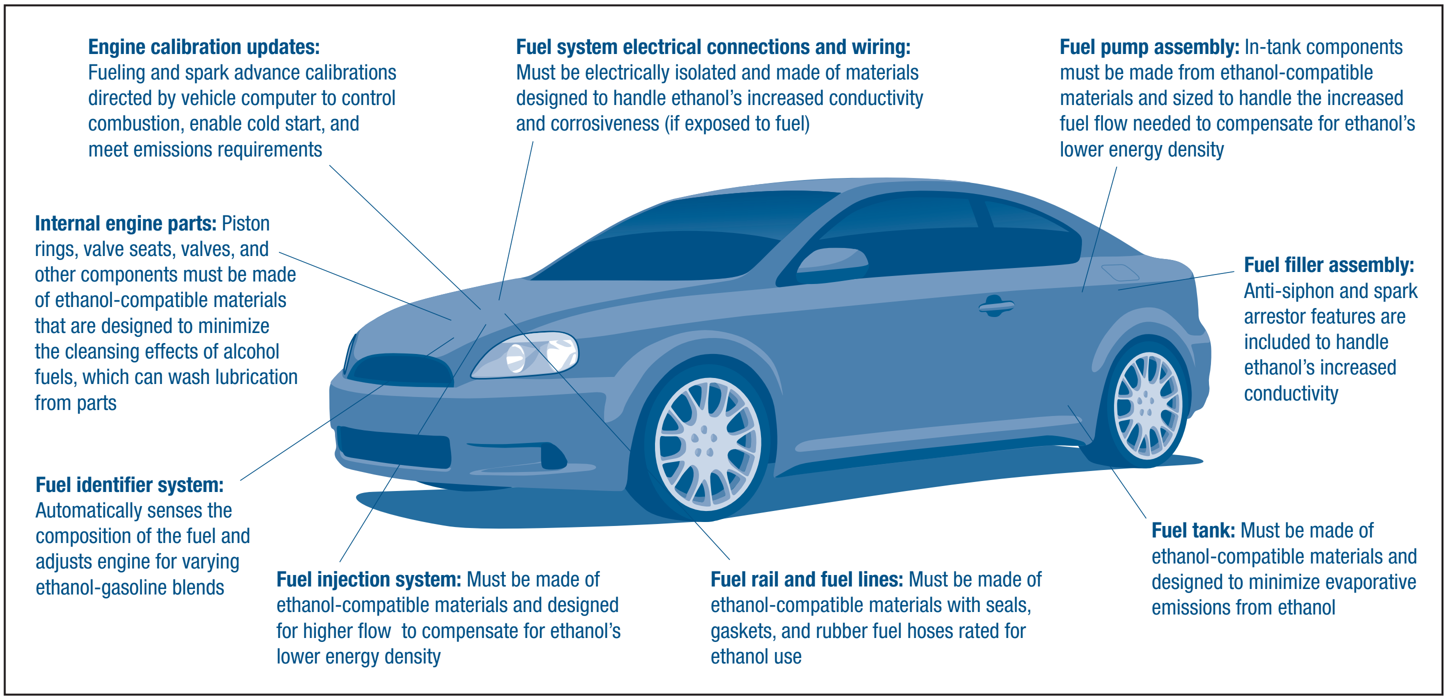
To date, certified FFV conversions are very limited. Using non-EPA-certified conversions is illegal and may affect vehicle warranties. To verify that a conversion system is legal for use in the United States and is compatible with their specific vehicles, consumers should request a copy of the supplier's EPA Certificate of Conformity or CARB Executive Order when considering converting their vehicles.

All major U.S. automakers as well as a few foreign manufacturers offer numerous FFV models at little or no incremental cost compared to a standard gasoline vehicle. Therefore, purchasing a new or used FFV produced by an original equipment manufacturer is a convenient option for vehicle owners looking for E85 compatibility.

What does the higher-octane level of E85 mean in terms of vehicle performance?

Octane rating is a measure of auto ignition resistance sometimes referred to as "knock resistance." The right amount of octane ensures that combustion occurs at the right time, delivers the most efficient power, and protects

Figure 1. FFV Components



[2] NREL. Alternative Fueling Station Locator. www.eere.energy.gov/afdc/fuels/stations_locator.html. Alternative Fuels and Advanced Vehicles Data Center. August 2008.

the engine from damage. Higher octane does not necessarily translate into higher horsepower. Technically, it can "allow" more horsepower if the engine and engine control system are designed to provide enough fuel and air and can optimize the combustion process to take advantage of the higher octane levels. However, current FFVs are typically optimized for gasoline and designed so drivers don't really notice a decrease in power or performance when the vehicle is running on E85.

Do miles-per-gallon ratings drop when ethanol is used in place of gasoline?

Yes, because ethanol contains less energy per gallon than gasoline. A gallon of 100% ethanol contains 76,000 British Thermal Units (BTUs) of energy, whereas a gallon of gasoline contains around 110,000 BTUs of energy. The number of miles per gallon will drop in direct proportion to the energy contained in the fuel, which amounts to a 25% reduction in the miles delivered per gallon of E85 versus gasoline.[3] However, if E85 is priced below gasoline, the cost-per-mile to operate may be comparable. For E10, the energy difference is only a few percent and typically not noticed in the vehicle's mileage performance.

Energy Balance

How much energy does it take to produce corn ethanol?

Corn ethanol's net energy value (NEV) is defined as the difference between the amount of energy available in a gallon of corn ethanol and the amount of fossil energy it takes to grow corn and process it into that gallon of fuel.

Assumptions in the NEV calculation include:

- Corn yields and crop inputs, such as fertilizers;
- Efficiencies in corn-to-fuel conversion technologies;
- Types of energy used to produce the ethanol;
- Credits for the energy available in the coproducts; and
- Range of factors used in production lifecycle evaluations.

NEV values are based on the amount of fossil energy used (i.e., petroleum, natural gas, coal) and do not include renewable energies (i.e., sunlight, biomass) used for growing corn or in biorefineries to generate heat used in the production process. This is primarily done for the purpose of evaluating ethanol as a viable replacement fuel for gasoline.

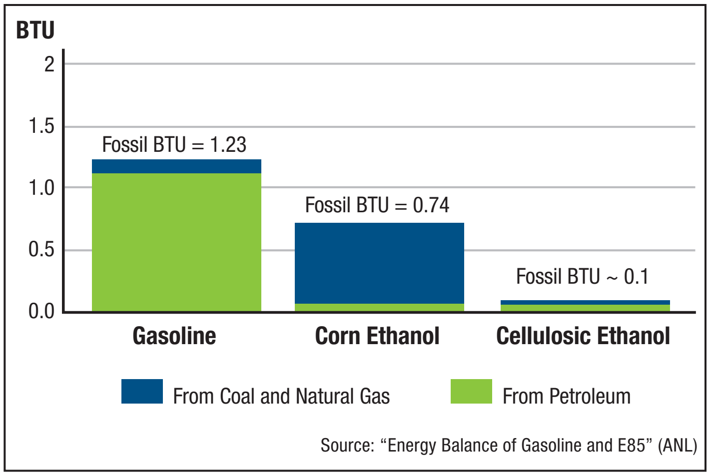
The NEV of corn ethanol production is improving as technology evolves. Although corn ethanol's NEV has been debated for years, the majority of studies published since the early 1990s show that corn ethanol can provide between 1.3 and 1.7 times more energy than the fossil energy it consumes during its production lifecycle.[4] This means that for every unit of energy delivered at the pump, corn ethanol production only requires 0.78 units of fossil energy, according to research conducted by DOE's Argonne National Laboratory (ANL).

The energy used to produce ethanol can also be compared to gasoline. Compared to the 0.78 units of fossil fuel required for corn ethanol production, gasoline requires 1.23 units. This means that the use of corn ethanol results in the consumption of 40% less fossil energy than the gasoline it replaces.[5]

Figure 2 shows the amount of fossil energy required to provide 1 BTU of each fuel at the pump. The graph does not reflect energy derived from solar or other renewable sources used in ethanol production.

Moving forward, cellulosic ethanol has an even higher energy balance than corn ethanol—delivering six times as much energy as is necessary to produce it. That's why DOE is focusing on research to develop processes to efficiently break down cellulosic feedstock components.

Figure 2. Fossil Energy Requirements for Gasoline and Corn and Cellulosic Ethanol (2007)



[3] NREL. "Flexible Fuel Vehicles: Providing a Renewable Fuel Choice." Alternative Fuels and Advanced Vehicles Data Center. www.eere.energy.gov/afdc/pdfs/42953.pdf.

[4] ANL. "Ethanol: The Complete Energy Life-Cycle Picture." www.transportation.anl.gov/pdfs/TA/345.pdf.

[5] ANL. "Ethanol: The Complete Energy Life-Cycle Picture." www.transportation.anl.gov/pdfs/TA/345.pdf.

Figure 3 illustrates the timeline of significant reports published on ethanol's NEV. Most of these studies found that ethanol has a positive NEV and their results are supported and used by DOE and the U.S. Department of Agriculture (USDA).

Greenhouse Gas Emissions

How do ethanol greenhouse gas emissions compare to those of gasoline?

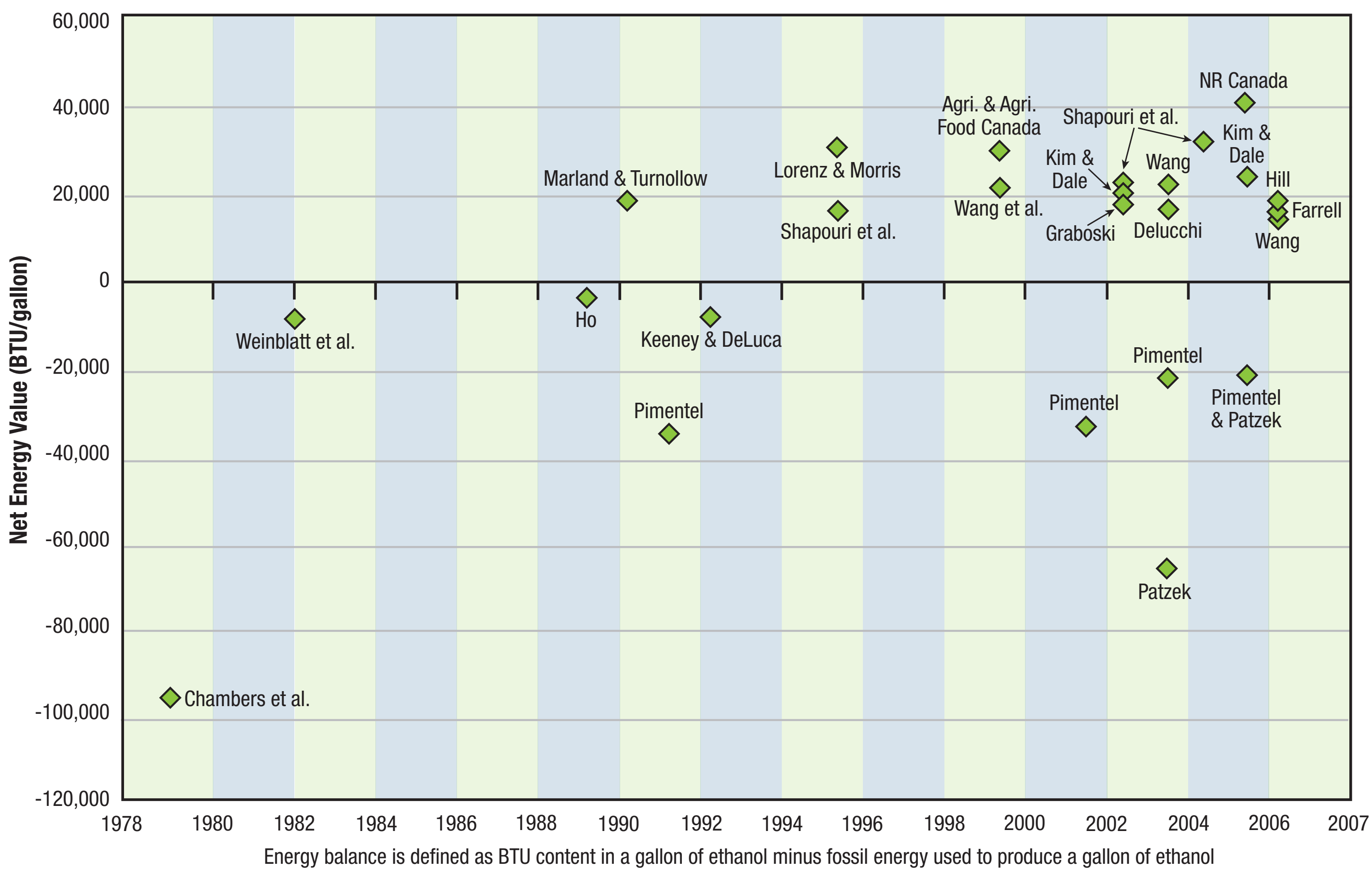
For a picture of the true greenhouse gas (GHG) reduction, lifecycle analyses are used to calculate GHG emissions at each step of production and use. For ethanol, these steps include growing the feedstock crops, transporting the feedstock to the production plant, producing and distributing the ethanol, and consuming it in vehicles. For gasoline, crude oil must be extracted from the ground, transported to a refinery, refined, distributed, and consumed in vehicles.

Recent analysis conducted by ANL[6] shows that when entire fuel lifecycles are considered, using corn ethanol instead of gasoline reduces GHG emissions by 19%-52% depending on the energy source used during ethanol production and the coproducts of the process. Biofuels produced using sustainable practices offer a significantly greater reduction in GHG emissions.

The fuel used to produce the energy used in the process has a significant impact on the GHG emissions (see Figure 4). Burning natural gas is much less GHG-intensive than coal because it contains substantially less carbon than coal per hydrogen carbon (energy producing) bond. Biomass emits fewer GHGs than natural gas because it actually pulls carbon dioxide out of the air when they are in the growth stages of its lifecycle.

Of the 102 ethanol production facilities operating in 2006, 98 used natural gas, two used coal, one used coal

Figure 3. Timeline of Significant Ethanol NEV Studies

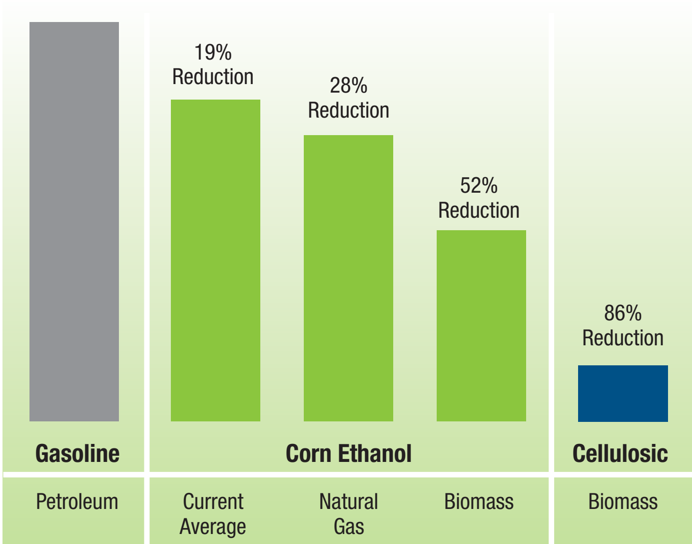


Energy balance is defined as BTU content in a gallon of ethanol minus fossil energy used to produce a gallon of ethanol

Source: Ethanol: "The Complete Energy Life-Cycle Picture" (ANL)

6 Wang, M.; May Wu; Huo H. (May 2007) "Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types." Environmental Research Letters. Volume 2, Number 2.

7 EPA. "Renewable Fuel Standard Program: Draft Regulatory Impact Analysis." www.epa.gov/oms/renewablefuels/420d06008.pdf.



Source: "Life-Cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types" (ANL)

and biomass, and one used syrup from the process to produce steam.[7]

Questions have also been raised about the impacts on GHGs if ethanol production results in direct or indirect land-use changes. This is an issue that is not yet well-understood, but the United States government is working to ensure ethanol production is sustainable. For example, as part of the Renewable Fuels Standard, the Energy Independence and Security Act of 2007 (EISA) requires EPA to enhance its GHG lifecycle analysis methodology for biofuels to include direct and indirect land use changes.

Food and Fuel

What effect does fuel ethanol have on food prices?

Estimates of the impact of biofuels on food prices vary widely. Many factors contribute to high retail food prices, including corn ethanol production. Other factors contributing to rising global food prices include:

- Higher costs of fossil fuels used to transport food to retail outlets,
- Increased demand as emerging economies grow and populations adopt better diets and eat more meat,
- Adverse weather in parts of the world and droughts leading to poor harvests,
- Devaluation of the dollar, which may reduce importing costs and increase export buying,
- Reduced global grain supply and increased demand for U.S. agricultural exports,
- Hedge funds and index funds buying of grain and oilseed futures,
- Growth in foreign exchange holdings by major food importing countries, and
- Reduction in global agriculture research and development slowing pace of yield increases.

The majority of U.S.-produced ethanol is currently made from field corn, which is grown to feed livestock. The production process yields coproducts of distiller's grains and gluten feed—both of which are fed to livestock, which helps minimize the impact on meat production. Wet-mill ethanol production facilities also produce starch, corn sweeteners, and corn oil—all of which are used as food ingredients for human consumption.

Does the use of ethanol impact gasoline prices?

According to recent reports, ethanol's production and increased availability is helping keep gasoline prices lower than they otherwise would be. The following excerpts support this theory.

- "The growth in ethanol production has caused retail gasoline prices to be $.20 to $.40 per gallon lower than would otherwise been the case."[8]
- "Oil and gas prices would be about 15% higher if biofuel producers weren't increasing their output."[9]
- "The use of 10% ethanol blend saved Missouri drivers $.077 per gallon at the retail pump in 2007."[10]

Water Impacts

Are there water-quality impacts associated with increased corn-crop acreages and the use of fertilizers and pesticides?

Increased land allotted for corn production and the use of fertilizers and pesticides to accelerate corn yields can result in higher amounts of nitrogen and phosphorous in waterways. In concentrations that are too high, these compounds can pollute waterways through surface runoff and groundwater. However, new water-conservation practices and fertilizer-efficiency techniques are now being used to increase corn yields and reduce agricultural water consumption and pollution. As required by EISA, EPA will monitor this issue as part of its assessment of the environmental impacts of biofuels and will publish a report on this topic in 2010.

[8] Du, X.; Hayes D.J.; "The Impact of Ethanol Production on U.S. and Regional Gasoline Prices and on the Profitability of the U.S. Oil Refinery Industry." 08-WP 467. 2008.

[9] "Wall Street Journal." March 2008.

[10] Urbanchuk, J.M. Impact of Ethanol on Retail Gasoline Prices in Missouri. www.mocorn.org/news/2008/LECG_MO_E10_Analysis.pdf.

Relative to corn, the production of cellulosic biomass feedstocks require lower inputs of water, fertilizers, and pesticides, accompanied by less erosion and improved soil fertility.

How much water is required to produce one gallon of ethanol?

According to a 2007 National Renewable Energy Laboratory (NREL) study,[11] 96% of the acreage used today to grow corn for ethanol has sufficient enough annual rainfall to not need supplemental irrigation. That is why corn is grown in humid climates like the Midwest, where very little supplemental irrigation is needed. Water required for the other 4% is approximately 1.2 acre-feet of water per acre, which is approximately 785 gal for every gallon of ethanol produced.

NREL's study also found that on average, the production process to produce 1 gal of ethanol requires 3 gal of water, while 2.5 gal of water are needed to produce 1 gal of gasoline. These estimates do not include water resources used for exploration and oil recovery.

Land Use and Soil Impacts

What impact does an increase in corn crops grown for ethanol production have on land use?

Of the 130% increase in corn productivity over the past 35 years, only 20% of the increase has come from expansion of crop land. Improved farming practices and new technologies are improving corn yields per acre, allowing growers to harvest considerably more corn without significantly increasing acreage. Biotech improvements to crop seeds have enabled farmers to adopt environmentally sensitive agricultural practices—such as no-till cultivation—that increase yields, while reducing the amount of water, fertilizer, and pesticide needed.

Potential land-use changes are an area of concern, however, reflected in EISA. The legislation expanded the national Renewable Fuel Standard to mandate 36 billion gal of biofuels annually by 2022. Of this, 21 billion gal must be advanced biofuels, which includes a requirement of 16 billion gal of cellulosic biofuel. Only biofuels made from feedstocks grown on land cleared for cultivation before December 2007 qualifies as advanced or cellulosic fuels under EISA. This provision was included to discourage detrimental land-use changes, such as tropical deforestation.

Growing cellulosic materials could require less fertilizer and land compared to growing corn. Higher fuel production rates for each ton of biomass decreases land use and requires significantly less water than corn ethanol.

Will soil quality be impacted by the harvesting of agricultural residues for use as cellulosic ethanol feedstock?

Soils are complex ecosystems composed of unknown numbers of organisms. The impact of crop residue removal may have on crop production and soil properties is an area of U.S. government investigation. EISA contains a provision that allows only domestic and imported renewable fuels that don't come from sensitive areas, and the USDA has invested $17 billion in programs requiring the adoption of environmental cropping practices since 2002.

Research is currently underway to determine how to combine residue collection with good soil conservation practices to maintain soil health. Two studies published so far are the USDA's field report, "Soil Health as an Indicator of Sustainable Management," and DOE's document, "Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda."

[11] Aden, A.; "Water Usage for Current and Future Ethanol Production." http://epw.senate.gov/public/index.cfm?FuseAction=Files.View&FileStore_id=3d2f1427-d51d-4a54-8739-166853ee1c44.

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