Ethanol

Quick Facts

- In 2008, 9.2 billion gallons of ethanol were consumed in the United States.
- As of 2007, a total of 110 corn ethanol plants were operating in 21 states.
- The Energy Independence and Security Act (EISA) of 2007 updated the federal Renewable Fuel Standard that requires the use of annually increasing amounts of corn ethanol. The updated mandate requires 11.1 billion gallons of corn ethanol in 2009 and increases yearly to 15 billion gallons in 2015. The mandate also requires that ethanol facilities, built after passage of the Act, must achieve at least a 20 percent reduction in lifecycle greenhouse gas emissions per gallon of ethanol relative to gasoline.

Background

Ethanol is made by fermenting sugars or starch into alcohol and can be used as a liquid fuel in motor vehicles. Most of the ethanol sold in the United States is blended with gasoline. Gasoline with up to 10 percent ethanol (E10) can be used in most vehicles without modification. Special flexible fuel vehicles can use a gasoline-ethanol blend that has up to 85 percent ethanol (E85).

Description

Ethanol can be produced from a variety of feedstocks, including cereal crops, corn, sugarcane, sugar beets, potatoes, sorghum, and cassava. Currently, only simple sugars or starches can be converted into ethanol on a commercial-basis; corn and sugarcane are the two main feedstocks. Researchers are examining other potential feedstocks for ethanol production, such as cellulosic biomass and other plant materials.

- **Corn ethanol**
  Corn-to-ethanol is currently the main commercial biomass-to-fuel pathway in the United States. To produce ethanol, starchy crops, like corn, first have to be converted to simple sugars before fermentation. This can be done through either wet or dry milling; currently, about 75 percent of corn ethanol in the United States is produced through dry milling and 25 percent through wet.

  - *In the dry milling process:*
    The corn kernel is first ground into a fine powder and mixed with water and enzymes to break the starch into sugar (glucose). The resulting mixture is heated to kill bacteria, cooled, and processed with other enzymes that break the glucose to dextrose. Yeast is then added to ferment the dextrose into ethanol and carbon dioxide (CO_2).

    The resulting ethanol has a high concentration of water, which must be separated from the ethanol via distillation. This distillation requires a large amount of energy, usually in the form of natural gas, to power the process. Dry milling results in a single co-product – distiller's dried grain with solubles (DDGS) – composed of protein and other nutrients and used as an animal feed.

  - *In the wet milling process:*
    The corn kernel is first soaked in a chemical solution and then separated into solid and liquid components. The starch is then is hydrolyzed, fermented, and distilled as in dry-milling.

Wet milling requires more equipment to process the corn than dry milling, but it is more suitable for larger refineries and results in more co-products that can be sold to other sectors.

- **Sugarcane ethanol**
  In Brazil, the primary feedstock for producing ethanol is sugarcane, with crop wastes (called *bagasse*) used for the conversion process energy. Sugarcane is about one-third simple sugar (sucrose) and two-thirds bagasse. To process the sugarcane, the sugar is pressed out of the cane and then fermented, a process similar to corn ethanol production. Bagasse provides energy for the processing and distillation, eliminating the use of fossil fuels from the manufacturing process.

- **Other feedstocks**

- Other feedstocks for ethanol production are emerging. Cellulosic feedstocks, such as perennial grasses (e.g., switchgrass and Miscanthus) or short rotation woody crops, can potentially be converted to ethanol.

Environmental Benefit / Emission Reduction Potential

The greenhouse gas (GHG) reduction potential can vary significantly based on how the feedstock is produced and how it is processed (e.g., what type of energy is used in the conversion process).

- On average, U.S. corn ethanol facilities, where natural gas is most commonly used for conversion energy, reduce life-cycle GHG emissions by about 20 percent per gallon of ethanol. With a coal-fired process, life-cycle GHG emissions for ethanol are 3 percent higher, relative to gasoline. If biomass power and carbon capture and disposal are used instead, ethanol can reduce emissions by more than 50 percent compared to gasoline.[1] These estimates only include the direct lifecycle emissions, and do not take into account indirect land use impacts.

- Brazilian sugarcane-based ethanol, which uses plant wastes for the conversion energy, reduces GHG emissions by 60 to 80 percent relative to petroleum, when considering direct lifecycle emissions.[2]

- Studies that have attempted to take into account the effects of ethanol production on land use generally have been more pessimistic about emission reductions and have calculated that GHG benefits of ethanol decrease significantly when the indirect land use impacts are considered.[3]

Table 1. Life-cycle GHG Intensity for Ethanol, based on the California GREET Model[4]

Fuel	Technology Used	CA GREET GHG (g CO_2e/MJ)
Corn Ethanol, U.S. Average	85% Dry Mill and 15% Wet Mill	68.6
Corn Ethanol, produced in Midwest	Dry Mill, Natural gas for power	67.6
Corn Ethanol, produced in Midwest	Wet Mill, 60% Natural gas and 40% Coal	74.3
Corn Ethanol, produced in California	Dry Mill, Natural gas for power	58.1
Sugarcane Ethanol		26.6
California Gasoline (including 10% ethanol)		95.9

Note: These estimates do not include the impact of indirect land use change on GHG emissions.

Cost

As with all biofuels, the costs of ethanol production depend greatly on the cost of the feedstock.

- **For U.S. corn ethanol:**
  In 2002, feedstock cost was about 57 percent of production cost for ethanol (EIA).

  When corn is available at $2.60 per bushel and natural gas at $5.70 per gigajoule, U.S. ethanol production costs are about $1.20 per gallon of ethanol, or $1.82 per gallon on a gasoline-equivalent basis (gge), a cost that includes a $0.40 per gallon credit from sale of co-products. Adding a 12-percent return on investment raises the cost to $1.33 per gallon of ethanol ($2.20 per gge).

  Every $1.00 per bushel rise in the price of corn increases the production cost of ethanol by $0.35 per gallon. Since 2006, the spot market price for corn has regularly exceeded $4.00 per bushel. At that price, ethanol production cost, including a return on investment, is about $2.77 per gge.

  In general, U.S. corn ethanol is competitive with gasoline (i.e., would not need a subsidy to compete in the market) when oil prices are in the $66 to $91 per barrel range compared to corn prices in the $2.60 to $4.00 per bushel range. Right now, U.S. corn ethanol receives a subsidy of 51 cents per gallon of ethanol that is blended with gasoline.

- **For Brazilian sugarcane ethanol:**
  Brazil produces sugarcane-based ethanol at costs significantly below those of corn-based ethanol—and, indeed, at lower costs than any other biofuel worldwide.

  The estimated cost of the Brazilian biofuel is $0.85 to $1.40 per gge. This makes Brazil's product at least 30 percent less expensive than U.S. ethanol from corn. In general, sugarcane ethanol is competitive with gasoline at oil prices in the $40 to $50 per barrel range.[5]

Current Status of Ethanol

With current technology, one bushel of corn yields approximately 2.8 gallons of ethanol,[6] or in terms of acreage, one acre of corn generates approximately 330-424 gallons of ethanol.[7] In comparison, sugarcane ethanol yields are more than 720 gallons per acre.[8]

Under requirements in the Energy Independence and Security Act of 2007, 9 billion gallons of ethanol were produced in 2008, which consumed about 30 percent of the U.S. corn crop. Studies suggest that devoting more than 25 percent of the crop to ethanol may result in substantial cost increase in corn prices.[9]

To produce more corn ethanol, producers have several options:

- Increase the amount of cropland in production,
- Increase the crop yields per acre, or
- Use more efficient processing techniques that increases the ethanol output from one bushel of corn.

Producers can also replace or supplement corn with other feedstocks, such as cellulosic products.

Obstacles to Further Development or Deployment of Ethanol

When assessing GHG emission reductions from biofuels, it is important to examine the full life-cycle emissions of the fuel. Land use changes, land management practices, biomass feedstock, conversion processes and type of energy used in conversion, and transportation of fuel to end users all affect the overall GHG profile of the fuel.

- **Land use for biofuel feedstocks**
  One of the main concerns with the increased use of ethanol is the impact on land use. Land-use changes occur for a variety of reasons, including the need to meet rising demand for food due to rising populations and incomes. As the price of ethanol increases, this creates pressure to convert previously idle land to crop production. Of particular concern is the conversion of forests, peatland, grasslands, or wetlands as a result of this process. On the other hand, land conversions, such as conversion of degraded lands to biofuel production, can have beneficial effects by increasing the ability of the soil to sequester carbon.

- **Transportation and use of ethanol**
  A number of key infrastructure issues will need to be addressed as ethanol production increases. Transporting ethanol to retailers requires an infrastructure separate from gasoline pipelines, because current pipelines are not designed to carry gasoline-ethanol mixes due to the propensity of ethanol to absorb contaminants and water. Transporting ethanol via truck increases both the cost and overall carbon footprint of the fuel. Furthermore, as ethanol production increases, higher level gasoline-ethanol blends (such as E85) are needed to absorb the additional ethanol. Using these higher level blends, in turn, requires special gas station pumps to dispense the fuel and flexible-fuel vehicles, both of which are currently limited in supply.

- **Impacts on other agricultural commodities**
  Producing ethanol from corn can also have an impact on food and feed prices. As ethanol consumption increases, corn is diverted from traditional food and feed markets to ethanol production. Although the exact nature of this increased demand for ethanol is uncertain, implications for agricultural markets will need to be considered as ethanol production increases.

- **Other environmental impacts**
  In addition to impacts on GHG emissions, ethanol production can also have other environmental effects. The increased use of fertilizers and pesticides to grow more corn or sugar cane can result in higher amounts of nitrogen and phosphorous run-off, affecting soil, air, and water quality. Growing feedstocks for ethanol also requires water for irrigation and processing, which can put a strain on local water supplies.[10] Converting land to ethanol production also impacts habitat and ecosystems in an area.

Moving forward, it will be important to take a critical look all available technologies and their GHG reduction potential to make sure corn ethanol can be produced cost-effectively and without harmful impacts on food prices and land use, and to transition to other feedstocks.

Policy Options to Help Promote Ethanol

Federal, state, county, and local governments currently support biofuels in a variety of ways. This support falls into two general categories: (1) policies that mandate levels of use for biofuels and (2) policies that offer subsidies or tax credits for biofuel production and/or use.

- **Mandates requiring biofuel use**
  The Energy Independence and Security Act of 2007 established a Renewable Fuel Standard that required the use of 9 billion gallons of corn ethanol in 2008, with mandated use levels increasing annually until 2015 when the requirement reaches 15 billion gallons.

- **Taxes and subsidies**
  Gasoline suppliers receive a 51-cent federal tax credit per gallon of ethanol blended with gasoline. After U.S. production and imports of ethanol exceeds 7.5 billion gallons, the credit decreases to 45-cents per gallon; this decrease is expected to happen in 2009.[11] Small ethanol producers (i.e., those with a production capacity of less than 60 million gallons a year) are eligible for a tax credit of 10-cents per gallon of ethanol produced on up to 15 million gallons in a given year.[12] Both of these tax credits will expire at the end of 2010 unless renewed by new legislation. On the other hand, imported ethanol incurs a 54-cent per gallon excise tax.

Future policy should take life-cycle emissions into consideration to ensure that corn ethanol production contributes effectively to greenhouse gas emission reductions. For more information on biofuel policies, see *CLIMATE TECHBOOK: Biofuels Overview*.

Related Pew Center Resources

Agriculture's Role in Greenhouse Gas Mitigation, 2006 http://www.pewclimate.org/global-warming-in-depth/all_reports/agriculture_s_role_mitigation.

CLIMATE TECHBOOK: Biodiesel, 2009 http://www.pewclimate.org/technology/factsheet/biodiesel

CLIMATE TECHBOOK: Biofuels Overview, 2009 http://www.pewclimate.org/technology/overview/biofuels

Biofuels for Transportation: A Climate Perspective, 2008 http://www.pewclimate.org/biofuels-transportation.

MAP: *State Mandates and Incentives Promoting Biofuels*
http://www.pewclimate.org/what_s_being_done/in_the_states/map_ethanol.cfm.

Further Reading / Additional Resources

U.S. DOE, Office of Energy Efficiency and Renewable Energy

- *Biomass Energy Data Book*, 2008 http://cta.ornl.gov/bedb/biofuels.shtml
- *Ethanol* http://www.afdc.energy.gov/afdc/ethanol/
- *Ethanol Basics*, 2008 http://www.afdc.energy.gov/afdc/pdfs/43835.pdf
- Ethanol: The Complete Energy Lifecycle Picture, 2005
  http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/ethanol_brochure_color.pdf

Renewable Fuels Association http://www.ethanolrfa.org/

Liska, Adam, et al. "Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol." *Journal of Industrial Ecology* 13(1): 58 – 74. 2008.

Searchinger, Timothy, et al. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change." *Science* 319(5867): 1238 – 1240. 2008.

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[1] Wang, M., M. Wu, and H. Huo. "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types." *Environmental Research Letters* 2 024001. 22 May 2007.

[2] International Energy Agency. 2007. "IEA Energy Technology Essentials: Biofuels Production." January 2007. http://www.iea.org/Textbase/techno/essentials2.pdf. Accessed 19 March 2009.

[3] Searchinger, T., et al. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change." *Science* 319. 29 February 2008.

[4] These life-cycle GHG intensities were calculated for the purposes of the California Low-Carbon Fuel Standard program. For more information on the analysis, see California Air Resources Board, Stationary Source Division. *Detailed California-Modified GREET Pathway for Brazilian Sugarcane Ethanol.* 12 January 2009. http://www.arb.ca.gov/fuels/lcfs/011209lcfs_sugarcane.pdf; California Air Resources Board, Stationary Source Division. Detailed California-Modified GREET Pathway for Corn Ethanol, Release Date: January 20, 2009. http://www.arb.ca.gov/fuels/lcfs/012009lcfs_cornetoh.pdf; and California Air Resources Board. Fuel GHG Pathways Update, Presentation: January 30, 2009. http://www.arb.ca.gov/fuels/lcfs/013009lcfs_pthwy.pdf.

[5] International Energy Agency. 2007. "IEA Energy Technology Essentials: Biofuels Production." January 2007. http://www.iea.org/Textbase/techno/essentials2.pdf.Accessed 19 March 2009.

[6] Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, National Research Council. *Transitions to Alternative Transportation Technologies: A Focus on Hydrogen.* Washington, DC: National Academies Press, 2007.

[7] Budny, Daniel, and Paulo Sotero. "Brazil Institute Special Report: The Global Dynamics of Biofuels." Brazil Institute of the Woodrow Wilson Center. April 2007. http://www.wilsoncenter.org/topics/pubs/Brazil_SR_e3.pdf. Retrieved on 2008-05-03.

[8] Ibid.

[9] Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, National Research Council. 2008. Transitions to Alternative Transportation Technologies: A Focus on Hydrogen. Washington, DC: National Academies Press.

[10] Chiu, Y., B. Walseth, and S. Suh. "Water Embodied in Bioethanol in the United States." Environmental Sciency and Technology 43. 10 March 2009. http://pubs.acs.org/doi/abs/10.1021/es8031067

[11] Yacobucci, Brent. 2009. Biofuels Incentives: A Summary of Federal Programs. Washington, DC: Congressional Research Service.

[12] Ibid.