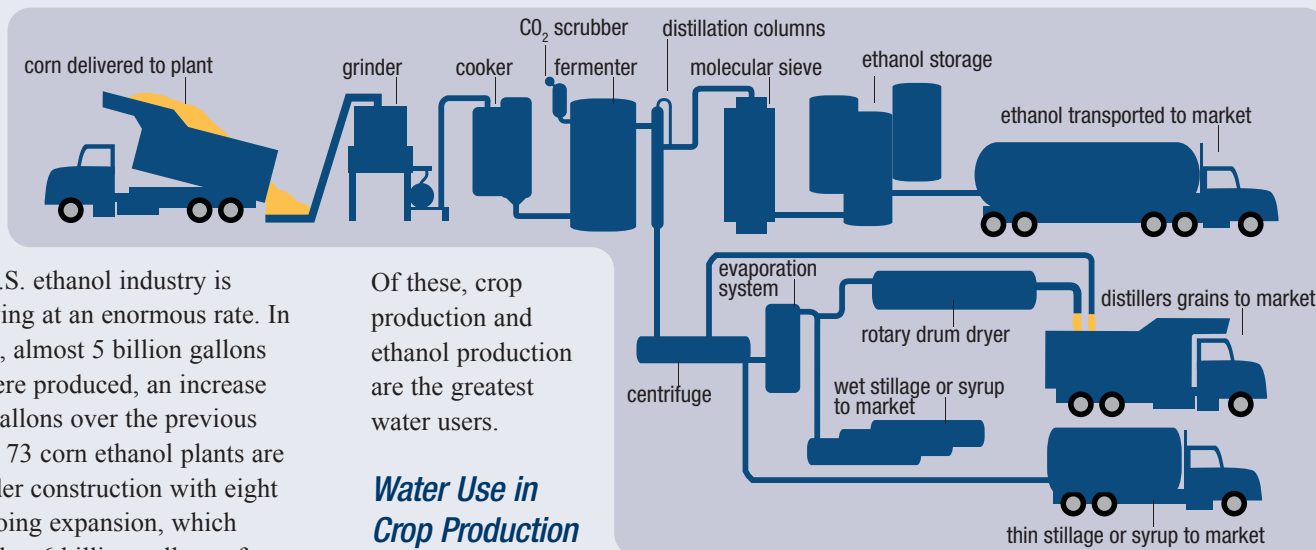


Water Usage for Current and Future Ethanol Production

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Dry grind corn ethanol production process (modified from Renewable Fuels Association, 2007)

The U.S. ethanol industry is growing at an enormous rate. In 2006, almost 5 billion gallons of ethanol were produced, an increase of 1 billion gallons over the previous year. At least 73 corn ethanol plants are currently under construction with eight more undergoing expansion, which will add another 6 billion gallons of new capacity by 2009. President Bush in his 2007 State of the Union Address established his “Twenty in Ten” goal of displacing 20 percent of gasoline in 10 years. This equates to 35 billion gallons of renewable and alternative fuels by 2017. With such rapid growth, water availability, utilization, and quality are key issues that must be addressed.

In 2006, the Institute for Agriculture and Trade Policy (IATP) issued a report describing why consumptive water use was one of the most important emerging concerns for the ethanol industry. Conflicts over water use in the Midwest are growing among agricultural processing facilities, livestock operations, and urban areas as water usage by each rises.

The most comprehensive methodology for analyzing and quantifying the water usage for a product such as ethanol is life cycle inventory and assessment (LCA). LCA quantifies material and energy flow rates across the entire life cycle of the fuel from cradle to grave. For ethanol, this includes: crop production and harvesting, transportation, ethanol production, and final utilization in a vehicle engine.

Of these, crop production and ethanol production are the greatest water users.

Water Use in Crop Production

The amount of water required to grow corn depends on local and regional considerations. As much as 96 percent of the field corn used for ethanol production is not irrigated at all. For corn that is irrigated, water consumption estimates are not widely available. The 2003 USDA Farm and Ranch Survey states that irrigated corn grain uses on average 1.2 acre-feet of water per acre of land. The average corn yield from this land is 178 bushels per acre. This equates to 785 gallons of water for every gallon of ethanol produced.

Water Use in Corn Ethanol Production

Two types of ethanol production processes are used in the United States: wet mill and dry grind. Over 80 percent of U.S. ethanol is produced from corn by the dry grind process depicted above. Corn grain is milled, then slurried with water to create “mash.” Enzymes are added to the mash and this mixture is then cooked to hydrolyze the starch into glucose sugars. Yeast ferment these sugars into ethanol and carbon dioxide and the ethanol is purified

through a combination of distillation and molecular sieve dehydration to create fuel ethanol. The byproduct of this process is known as distiller’s dried grains and solubles (DDGS) and is used wet or dry as animal feed.

Many of these ethanol plants have little or no wastewater discharge. They recycle a significant portion of their process water through a combination of centrifuges, evaporation, and anaerobic digestion. Therefore, water demand primarily is related to energy production, specifically the cooling tower and boiler systems.

Estimates of water usage during ethanol production range from 3 to 4 gallons of water per gallon of ethanol produced. IATP (2006) states that Minnesota ethanol plants in 2005 averaged 4.2 gallons of water per gallon of ethanol produced. Other industry experts calculate ratios closer to 3:1. Thus, a 50-million-gallon per year ethanol facility can expect to use 150 to 200 million gallons of water per year, or over 400,000 gallons per day (1.2 acre-feet). In the corn belt, the source of this is often groundwater.

How does this usage compare to other industries and processes? Petroleum refining, for example, has the highest rate of water recycling of any major industry. Water use ranges between 65 and 90 gallons per barrel of crude oil processed and wastewater discharge ranges between 20 and 40 gallons, leaving 45 to 50 gallons of water consumed per barrel, or 2 to 2.5 gallons of water per gallon of gasoline. However, the ratio is lower if all fuel products are considered (diesel, kerosene, etc). Power plants, however, consume significantly more water because they have greater cooling needs. A coal-fired power plant on average will use 9.5 gallons per minute per megawatt (MW). For a 250 MW power plant, that equates to 3.4 million gallons per day. And nuclear power plants use 25 percent more water than an equivalent coal-fired power plant.

Water Use in Cellulosic Ethanol Production

Cellulosic ethanol technology is also rapidly becoming a reality. At the National Renewable Energy Laboratory (NREL), scientists and engineers continue to research and develop the technology to convert biomass into fuels such as ethanol. Biomass feedstocks range from agricultural residues (corn stover, wheat straw) to woody feedstocks, and include energy crops such as switchgrass, which is more drought tolerant than corn and can be grown over a wider geographic area.

An NREL report (Aden and others, 2002) documents a detailed process design and economic analysis for the conversion of corn stover to ethanol. Similar to corn ethanol production, a combination of enzymes and fermenting organisms are used in this biological approach, but the process is more complex. For example, cellulose is much more difficult to break down. A mixture of sugars is fermented instead of a single sugar, and the presence of the byproduct lignin compounds the technical difficulty of this process. Using this design, 69.3 million gallons per year of ethanol are produced, and 6 gallons of water are used per gallon of ethanol produced. This is a non-optimized process with potential for improvement.

Fresh Water Demands	Corn Ethanol: Dry Grind	Cellulosic Ethanol: Biochemical	Cellulosic Ethanol: Thermochemical
Cooling tower makeup (percent)	68	71	71
Boiler and process makeup (percent)	32	29	29
Overall water demand (Gal H ₂ O / Gal EtOH)	3-4	6	1.9

Summary of ethanol production process water demands. Corn ethanol values are from commercially operating plants; cellulosic values are model-based.

As with corn, most of the water demand is related to energy production.

Similarly, a 2007 NREL report (Phillips and others, 2007) documents a detailed process design and economic analysis for the conversion of wood chips to ethanol via a thermochemical approach, using low pressure gasification followed by mixed alcohol synthesis. However, this report documents steps that were taken to minimize water usage, such as using forced-air cooling in place of cooling water when possible. In this primary design consideration, the water usage for this process was calculated at 1.9 gallons of water per gallon of ethanol.

Opportunities for Water Savings

Given this information, it becomes clear that the energy and water demands of ethanol processes are closely integrated, and one way to reduce water demand is to reduce energy consumption. Many options are being pursued in this category. Producing broths with higher ethanol concentrations can reduce the energy needed for distillation. Alternative technologies to distillation, such as pervaporation (a membrane separation process), also have the potential to significantly reduce water usage.

A second option for reducing water demand is to utilize a different heat transfer medium, using forced-air fans for cooling instead of water where appropriate. This could potentially result in much lower evaporative and blowdown losses. In addition, new patented water

conservation technology has resulted in cooling towers with 20 percent reduction in water consumption (Owens, 2007) and new high efficiency dryer designs. Several of these options are currently being modeled at NREL to determine potential water, energy, and economic benefits for the cellulosic processes.

DOE is also in the process of examining water use issues associated with the growth of a biomass to fuels and chemicals industry in the United States. Specifically, water issues related to increased feedstock production (such as water availability and competing water use rights) needed to meet renewable fuel goals for the future will be studied. These must be quantified in terms of current and projected increases in feedstock production.

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References.....

- Aden, A., M. Ruth, K. Ibsen, J. Jechura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, A. Slayton, and J. Lukas, 2002. Lignocellulosic biomass to ethanol process design and economics utilizing co-current dilute acid prehydrolysis and enzymatic hydrolysis for corn stover, NREL/TP-510-32438, www1.eere.energy.gov/biomass/pdfs/32438.pdf.
- Institute for Agriculture and Trade Policy (IATP), 2006. Water use by ethanol plants potential challenges, Minneapolis, MN. www.agobservatory.org/library.cfm?refid=89449
- Owens, S., June 2007. Reduce cooling tower water consumption by 20%, Ethanol Producer Magazine, www.ethanolproducer.com
- Phillips, S., A. Aden, J. Jechura, and D. Dayton, 2007. Thermochemical ethanol via indirect gasification and mixed alcohol synthesis of lignocellulosic biomass, NREL/TP-510-41168, www.nrel.gov/docs/fy07osti/41168.pdf.
- Renewable Fuels Association, 2007. How ethanol is made, www.ethanolrfa.org/resource/made/

The Numbers

- 96% of corn used for ethanol production is not irrigated
- 785 gallons water per gallon of ethanol (average crop irrigation)
- 3-4 gallons water per gallon ethanol (dry grind production)
- 1.9-6 gallons water per gallon ethanol (conceptual cellulosic production)
- 2-2.5 gallons water per gallon gasoline (petroleum refining)
- 0.6 gallons water per kilowatt-hour (coal-fired power plant)