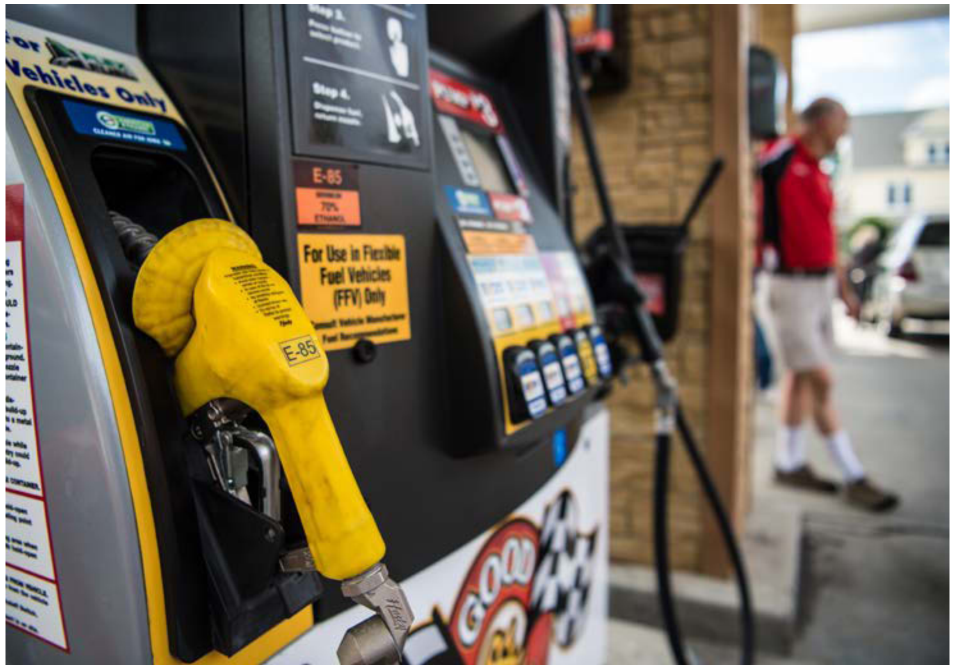
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Ethanol Basics

Ethanol is a widely used, domestically produced renewable fuel made from corn and other plant materials. Ethanol can be blended with gasoline in different amounts. In fact, more than 98% of gasoline sold in the United States contains ethanol to oxygenate the fuel and help to reduce air pollution.[1] Using ethanol in fuel also helps the nation increase the use of domestic alternative fuels, thereby potentially reducing reliance on imported oil. Gasoline and gasoline blendstocks can also use ethanol as an octane enhancer to increase vehicle performance.



Ethanol may be labeled in a variety of ways at the pump. *Photo by Dennis Schroeder, NREL 47090*

What ethanol blends are available?

Nearly all fuel-grade ethanol is sold as E10, a low-level blend of 10% ethanol, which is approved for use in all conventional light-duty vehicles. E15 (10.5%–15% ethanol) is approved for use in model year (MY) 2001 and newer light-duty conventional vehicles. To use E85, a high-level blend containing 51%–83% ethanol (depending on geography and season), a vehicle must be a flexible fuel vehicle (FFV). Intermediate blends between E15 and E85 are also approved for FFVs. These blends are typically available through blender pumps, which draw fuel from two storage tanks—one containing regular gasoline, and another containing E85. The most common blends are E20 and E30.

What is an FFV?

An FFV, as its name implies, has the flexibility of running on more than one type of fuel. FFVs can be fueled with unleaded gasoline, E85 (flex fuel), or any combination of the two. Like conventional gasoline vehicles, FFVs have a single tank and fuel system. However, FFVs differ in fuel-system materials and control systems to account for ethanol content (Figure 1). There are currently more than 20 million FFVs registered in the United States.[2] However, many FFV owners don't realize their car is an FFV and that they have a choice of fuels. An FFV is often distinguished by an emblem on the back of the vehicle, and some FFVs have yellow fuel caps. To find FFV models, see the Alternative Fuels Data Center's (AFDC) Alternative Fuel and Advanced Vehicle Search (*afdc.energy.gov/vehicles/search/*).

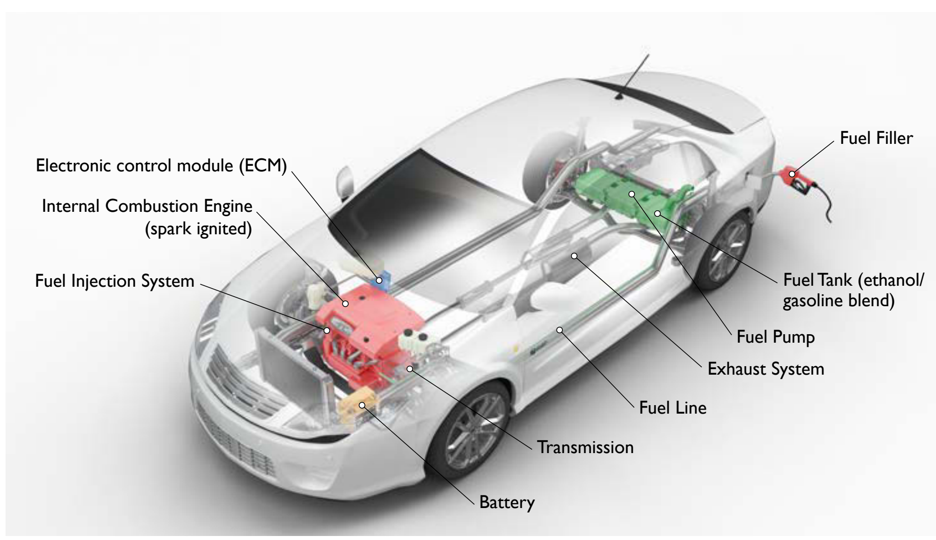


Figure 1. FFV Components. *Illustration by Josh Bauer, NREL*

1 *Pocket Guide to Ethanol 2017*, Renewable Fuels Association, *http://www.ethanolrfa.org/wp-content/uploads/2017/02/Pocket-Guide-to-Ethanol-2017.pdf*

2 Vehicle populations were determined using 2016 Polk vehicle registration data purchased by the National Renewable Energy Laboratory.

Online Resources

Take advantage of the following online resources to learn more about alternative fuels like ethanol and where to refuel:

- **Ethanol Handling and Use Guide:** Use this handbook to learn basic information regarding fuel properties, standards, codes, and the proper and safe use of E85 and other ethanol blends, with supporting technical and policy references included (*afdc.energy.gov/uploads/publication/ethanol_handbook.pdf*).
- **Alternative Fueling Station Locator:** Find alternative fueling stations and electric vehicle charging locations in your area by visiting the website (*afdc.energy.gov/stations*) or downloading the iPhone or Android app.
- **Vehicle Technologies Office Technical Response Service:** Let seasoned experts answer your questions about alternative fuels, advanced vehicles, fuel economy, and idle reduction (*technicalresponse@icf.com*; 800-254-6735).

Most ethanol is currently derived from field corn. Ethanol can be made from a variety of plant-based feedstocks such as prairie grasses, wood chips, wheat leftovers, switchgrass, and miscanthus (pictured). *Photo by Dennis Schroeder, NREL 47114*

How can I find ethanol blends?

E15 is available at approximately 1,400 stations. Additionally, there are currently about 3,200 public E85 fueling stations in the United States. To locate E85 stations in your area, see the Alternative Fueling Station Locator (*afdc.energy.gov/stations*).

How is ethanol produced?

Corn ethanol is primarily produced using dry mill technology, which is a process that grinds corn into flour and ferments only the starch into ethanol. Approximately 90% of ethanol is made this way. The remaining components of corn are made into co-products like corn oil and distillers grains, which are used as livestock feed. As of January 2017, the country had an annual capacity of more than 15.5 billion gallons.[3]

What is cellulosic ethanol?

Cellulosic ethanol is produced from non-food feedstocks that are either waste products or purposefully grown as energy crops and harvested from marginal lands not suitable for other crops. Corn stover, switchgrass, and miscanthus are a few examples of cellulosic ethanol feedstocks. While these feedstocks offer many advantages over starch- and sugar-based feedstocks, there are challenges with harvesting, collecting, and delivering them. Currently, cellulosic ethanol is being sold commercially in small volumes. To learn more, visit the AFDC's Ethanol Production and Distribution page (*afdc.energy.gov/fuels/ethanol_production.html*).

How much energy is used to produce ethanol?

Ethanol produced from corn grain and cellulosic materials results in a positive energy balance, meaning the fuel contains more energy than the amount of energy required to produce it. Moreover, using cellulosic feedstocks results in a dramatic energy balance improvement. Using biomass to power the process of converting cellulosic feedstocks into ethanol can further increase the energy balance. For more information, see the AFDC's Lifecycle Energy Balance page (*afdc.energy.gov/vehicles/emissions_balance.html*).

How well does ethanol perform?

Ethanol has a higher octane number than gasoline, which provides increased power and performance in an optimized engine. For example, Indianapolis 500 drivers often fuel their race cars with E98 because of its high octane. The

3 "U.S. Fuel Ethanol Plant Production Capacity, June 2017 with Data for January 2017," U.S. EIA, *https://www.eia.gov/petroleum/ethanolcapacity/*

Plants like this one in Nevada, Iowa, commonly use dry mill technology to process corn into fuel-grade ethanol and distiller's grains. *Photo by Dennis Schroeder, NREL 47103*

U.S. Department of Energy's (DOE) Co-Optimization of Engines and Fuels initiative conducts coordinated engine and fuels research and analysis, providing the framework for the co-development of fuel and engine technologies that offer the greatest combination of efficiency, performance, and fuel diversification. As part of this initiative, researchers are exploring how blendstocks, including ethanol, can improve performance. Ethanol contains less energy per gallon than gasoline—a gallon of pure ethanol (E100) has 76,330 British thermal units (Btu) of energy while a gallon of gasoline typically contains about 114,000 Btu. The impact on fuel economy (miles per gallon) will depend on the ethanol content of the fuel, up to a maximum 25% reduction for E85 (assuming 83% ethanol content compared to pure gasoline. The impacts of E10 or E15 are proportionally smaller; drivers will generally not notice a difference in a vehicle's fuel economy. Engines in gasoline vehicles, including FFVs, are optimized for gasoline. If they were optimized to run on higher ethanol blends, fuel economy would increase.

How do ethanol life-cycle CO_2 emissions compare to gasoline?

To determine a fuel's emissions impact, it is important to consider the full "life cycle" (which includes every step in the fuel's production and use). For ethanol, the life cycle includes growing the feedstock and delivering it to the ethanol plant, and then producing, distributing, and using the fuel in vehicles. The life cycle steps for gasoline include crude oil extraction, transportation to a refinery, the oil's conversion into gasoline, then distributing and using the fuel in vehicles. An analysis conducted by Argonne National Laboratory found that, when entire life cycles are considered, corn ethanol reduced greenhouse gas emissions by an average of 34% over traditional fuels. Depending on the feedstock, emissions reductions of cellulosic ethanol compared to conventional gasoline range from 51% to 88% when land-use change emissions are considered. ■

FFVs are available in a wide range of models, such as sedans, pickup trucks, and minivans. *Photos from Mark Bentley, NREL 31747 and John De La Rosa, NREL 27783 and 27780*

Case Study: City of Chicago Program Encourages Alternative Fuel Use and Collaboration Between Departments

Successfully transitioning a fleet to alternative fuels requires investment in fueling infrastructure and a strong commitment to modifying driver behavior. Motivated by energy security, economics, and emissions reduction goals, the City of Chicago fleet began its journey by acquiring E85 FFVs in 1995. Today, it has more than 3,000 light-duty FFVs in law enforcement and municipal applications. The City of Chicago annually uses about 1.13 million gallons of E85, making the city the largest user of E85 in the Chicago metropolitan area.

Fleet drivers expressed a genuine interest in E85 after the initial FFV roll-out. But with only six E85 fueling stations available to support more than 1,000 FFVs, the city quickly realized the need for E85 infrastructure expansion. Initially, the city lacked the funds to support such a project, but officials worked with the Chicago Area Clean Cities (CACC) to develop project goals, cost estimates, and timelines. Being prepared with these plans allowed the city to take advantage of a funding opportunity when it arose.

A customer pumps E85 at a public fueling station. *Photo by Dennis Schroeder, NREL 47094*

CACC secured $700,000 in funding, half through DOE and the remainder matched by the city. By expanding the city's private E85 fueling infrastructure to a total of 11 stations, the Chicago Department of Fleet and Facility Management and the Chicago Department of Environment determined the city could achieve an 11-fold increase in E85 use by 2011.

With funding secured and planning complete, the city broke ground at five new E85 fueling sites in January 2010 and completed all work by March 2012. During this time, the city expanded the number of FFVs in its fleet to more than 1,500 vehicles.

To maximize alternative fuel use, the city developed a "lockout" policy for its FFVs: Using the existing fuel management system, the fleet requires all city FFVs to fuel with E85 when at city fueling stations. Drivers enter vehicle identification numbers at the city's fueling kiosks, and the fuel management system directs FFV drivers to proceed to E85 dispensers.

E85 consumption skyrocketed after the lockout policy was implemented, hitting approximately 600,000 gasoline gallon equivalents (GGEs) in the second quarter of 2012. The city was pleased with the policy's effectiveness, but challenges began to arise when E85 became significantly more expensive than gasoline on a GGE basis.

"It's easy to get the vehicles. The tough part is the infrastructure. After that, the key is to keep an eye on the price and make sure it continues to be economically practical," said Samantha Bingham, CACC coordinator and environmental policy analyst at the Chicago Department of Transportation.

The City of Chicago's fleet includes more than 3,000 light-duty FFVs in law enforcement and municipal applications. *Photo from Walter S. Mitchell, courtesy of the City of Chicago, NREL 29548*

The city had to find the right balance between environmental and financial sustainability. So, it enacted a strategic plan to remove the blanket lockout policy and instead base its E85 fueling requirements on daily price differentials between gasoline and E85.

Under the new plan, the Chicago Department of Fleet and Facility Management re-institutes the lockout policy when E85 prices are equal to or less than gasoline prices. It places the fueling decision in the hands of individual drivers during the "policy-free" periods. Even with the policy modification, the fleet's E85 use is consistently higher than it was before the E85 infrastructure expansion. The city is also committed to working with fuel suppliers to find ways to keep the price of E85 below that of gasoline, and it is considering options to decouple the alternative fuel and conventional fuel contracts.

With CACC's assistance, the city has been able to achieve several key goals outlined in its Sustainable Chicago 2015 Action Agenda (*cityofchicago.org/city/en/progs/env/sustainable_chicago2015.html*). These include expanding infrastructure in Chicago and reducing 2012 baseline fossil fuel consumption levels by 10% through the use of alternative fuels and advanced technologies. The coalition also assists the city in quantifying its emissions reductions through tools such as the GREET Fleet Footprint Calculator (*afdc.energy.gov/tools*).

Looking ahead, the city plans to continue to increase the number of alternative fuel and advanced vehicles in the fleet by 10% per year, and CACC will ensure that the city stays aware of funding and networking opportunities.

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For more information, visit: afdc.energy.gov

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