Environmental and Energy Study Institute

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Fact Sheet

# High Octane Fuels: Challenges & Opportunities

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While internal combustion engines are more efficient and cleaner than ever, the transportation sector is still responsible for 27 percent of greenhouse gas (GHG) emissions, with half of all transportation emissions coming from light-duty passenger vehicles.[1] The Energy Information Administration predicts the internal combustion engine will be the dominant engine for the next several decades, making both fuel and engine efficiency critical pieces in reducing the GHG intensity of the transportation sector.[2] Federal regulations that require the increased use of renewable fuels (Renewable Fuels Standard or RFS) and improvements in vehicle fuel economy (Corporate Average Fleet Economy or CAFE) have spurred an examination of mid-level ethanol blends and their potential to make the light duty fleet more efficient.[3]

Researchers from Argonne National Laboratory (ANL), the National Renewable Energy Laboratory (NREL), and Oak Ridge National Lab (ORNL) have been conducting coordinated studies to address the opportunities and challenges of deploying high octane fuels with mid-level ethanol blends to the passenger vehicle fleet. They are finding that fuels that blend between 25 to 40 percent ethanol (E25 to E40) with conventional gasoline, instead of the current 10 percent ethanol blend (E10), can lead to greater fuel efficiencies and lower overall GHG emissions in the existing passenger fleet. Additionally, the introduction of this high octane mid-level ethanol fuel could provide an optimized fuel source for the much more efficient internal combustion engines carmakers are developing.

## Mid-Level Ethanol Blends

### Ethanol Use in the United States

More than 95 percent of the gasoline sold in the United States today contains ten percent ethanol (E10).[3] In addition to lowering the CO2 intensity of gasoline, ethanol also improves the octane rating of gasoline. Ethanol is a renewable fuel sourced from corn as well as other agricultural feedstocks and organic wastes. In 2014, the United States produced 14.34 billion gallons of ethanol[4]; ethanol blending in the United States is governed by the Renewable Fuel Standard (RFS).

Passed in 2005, the RFS sets blending requirements of renewable fuels in the transportation fuel supply and as such is the primary driver of domestic biofuels production in the United States. There are two biofuel categories: total renewable fuels (which include corn ethanol) and advanced biofuels, which include biomass-based biodiesel, cellulosic and agricultural waste-derived biofuels, and other advanced biofuels. Each fuel category has specific volume targets and greenhouse gas (GHG) emission reduction thresholds relative to conventional gasoline. Conventional ethanol must reduce GHGs by 20 percent, and cellulosic ethanol must reduce GHGs by 60 percent. According to research from Argonne National Laboratory, production of conventional ethanol in the United States reduces lifecycle GHG emissions between 19 to 48 percent, relative to gasoline.

### The "Blend Wall"

In the United States, the majority of ethanol is used as part of the standard E10 blend. Conversely, E85 (85 percent ethanol, 15 percent gasoline) makes up less than one percent of total ethanol consumption. To increase the total volume of ethanol used to more than 10 percent by volume of the fuel supply (this threshold is commonly referred to as the "blend wall"), investments in gasoline infrastructure and compatible vehicles are needed to integrate higher blends (e.g. E15, E25, E40) into the retail fuel environment.

However, the challenges presented by the "blend wall" are overstated. Research from the National Labs finds that a significant portion of the existing fleet and fuel infrastructure can accommodate mid-level ethanol blends without significant cost. In addition to dedicated vehicles that can use higher ethanol blends, EPA and DOE have certified the use of E15 (15 percent ethanol) in cars of make and model year 2001 and newer—that is, more than 80 percent of cars on the road today. Vehicle manufacturers have also certified the use of E15 in two-thirds of the U.S. market for model year 2015 vehicles.[5]

Already, the market for E15 blends is increasing slightly. According to the Renewable Fuels Association, E15 is currently being offered to make and model year cars newer than 2001 by 109 retail gas stations in 16 states, a market that has grown mostly in the past few years.[6] If pending legislation (S. 1239 and H.R. 1736) to extend a fuel volatility waiver to blends higher than E10 is passed, E15 may be offered at an increasing number of retail gas stations.[7]

## Octane: Properties, Sources and Use

### Octane

The octane rating is a measure of a fuel's ability to avoid knock. Knock occurs when fuel is prematurely ignited in the engine's cylinder, which degrades efficiency and can be damaging to the engine. Before the introduction of unleaded gasoline in the mid-1970s, these 'anti-knock' properties were provided by lead. The 1990 *Clean Air Act* amendments fully banned the use of lead in gasoline in the United States. Today, the octane boost to prevent knocks is provided by gasoline aromatics, which comprise more than 25 percent by volume of each gallon of gasoline.[8]

Fig. 1: octane rating of gasoline, as displayed at a typical gas station.

The primary sources of octane are petroleum refinery products, and ethanol. At most retail gasoline stations, three octane grades are offered, 87 (regular), 89 (mid-grade) and 91-93 (premium). The higher the octane number, the more resistant the gasoline mixture is to knock. Use of higher octane fuels enables higher compression ratios, turbocharging, downsizing/downspeeding, all of which enable greater engine efficiencies.[3] Currently, high-octane fuel is marketed as 'premium,' but future combustion engines may require higher octane fuels to reach even greater engine efficiencies and higher mile-per-gallon ratings. At ORNL, researchers are investigating the benefits of ethanol as a renewable octane provider.

## Vehicle and Infrastructure Compatibility

### Vehicles

Today, there are 17.4 million FlexFuel Vehicles (FFVs) on the road.[9] The majority of FFVs have been produced by General Motors, Ford, and Chrysler.[9] These cars can use blends of up to 85 percent ethanol. However, an average FFV only uses an estimated 13.4 gallons of E85 per year, likely due to a combination of factors, including shortage of ethanol fuel availability at retail gas stations, as well as pricing and insufficient consumer knowledge.[3] According to the National Labs, a mid-level ethanol blend (E20 to E40) can be used in the existing FFV fleet, and provide a commercially available fuel for future engines that are optimized to use such a fuel.[3,9]

Researchers from ORNL tested two fuel blends (E10 and E30) on four different late-model FFVs, and two fuel blends (E0 and E15) on a conventional, Gasoline-Direct Injection (GDI) non-FFV vehicle. They found an increase in performance when ethanol content was increased from E10 to E30 for three out of four FFVs tested. An E15 fuel blend demonstrated improved efficiency and acceleration performance in a conventional GDI engine, compared to neat gasoline (E0).[9] In addition to providing enhanced performance for current FFVs, the results are promising for future optimization of engines and fuel for increased fuel economy.

| Ethanol Blend | E0 | E10 | E15 | E30 |
|---|---|---|---|---|
| Octane rating (anti-knock index) | 87.4 | 88.2 | 92.6 | 94.4 |
| Research octane (RON) | 90.7 | 92.4 | 97.8 | 100.7 |
| FlexFuel Vehicle compatible | Y | Y | Y | Y |
| Make and model 2001 and newer compatible | Y | Y | Y | N |

Table 1: Fuel blends tested by ORNL.

### Infrastructure – Tanks and Pumps

To use higher blends of ethanol, both underground storage tanks and above ground infrastructure compatibility must be assessed at retail gas stations. While mid-level ethanol blends do require some changes to the current gasoline infrastructure, the challenges may be overstated. Currently, a wide variety of Underwriters Laboratory (UL) certified equipment for blends between E15 and E85 are available to retail gas station owners. Despite this availability, in late 2014, there were only approximately 2,400 E85 retail gasoline stations in 37 states; 342 of these stations could mix mid-level ethanol blends on-site.[3] According to research from NREL, the majority of underground storage tanks are able to store blends up to E85, but retailers must demonstrate that their tanks are compatible and decide what storage tanks to devote to which fuels. In addition to tank compatibility, other above-ground component compatibility issues will need to be considered for a gas station to sell blends higher than E10. In general, infrastructure upgrades for E85 fueling represent a much more significant cost to individual retail gas station owners than mid-level blends containing up to 25 percent ethanol.

| Equipment cost | E15 – E25 | E26 – E83 |
|---|---|---|
| Total cost; existing underground tank | $4,435 | $25,926 |
| Total cost; new underground tank | $97,935 | $119,426 |

Table 2: Minimum costs for one mid-level refueling position at a retail gas station, as calculated by NREL.

It is difficult to assess the exact cost for individual retailers to be able to offer mid-level ethanol blends; upgrades may range from simple signage changes to completely new fueling equipment. Testing a blend of E17 in new and used Underwriters Laboratory refueling equipment, NREL found 56 percent of the tested equipment was compatible.[3] Costs for equipment needed to utilize blends between E15 and E25 was moderate compared to higher blends.

The cost of manufacturer-approved equipment capable of dealing with E26 to E85 blends is viewed as a serious impediment to greater market penetration of mid-level blends. Additionally, owners who own a large number of stations (such as big-box stores) are concerned with the complexity of regulations around such fuels, and are not likely to begin offering these fuels until there is market penetration equivalent to about 20 percent of retail fueling stations, according to estimates.[3]

## Market Analysis

Researchers from NREL have also conducted a market analysis of the regional appropriateness of alternative fuels, including ethanol (E85), biodiesel, compressed natural gas (CNG), electricity, and propane.[10] Factors considered included proximity to fuel stations, number of alternative fuels vehicles, gasoline prices, state level programs and incentives, proximity to fuel resources (e.g. proximity to an ethanol refinery), and environmental benefits.

According to the findings, while neat ethanol may be trading at a significantly lower price than gasoline at any given time, retailers often peg E85 to E10 prices.[10] Therefore, savings may not be passed on to the consumer. Currently, it is unclear what overall pricing strategy would be used in the widespread deployment of a mid-level blend, but without providing savings to consumers, it is difficult to market fuels directly to consumers on a cost-basis.

The strongest E85 markets are in the Midwest, due to their proximity to feedstock growth and ethanol refining facilities. Additionally, these states have more refueling infrastructure, spurred on by robust state incentives. Urban areas with strong markets for E85 include the San Francisco Bay, Los Angeles, Denver, New York City, Rochester-Buffalo, Houston, Miami, and Dallas.[10]

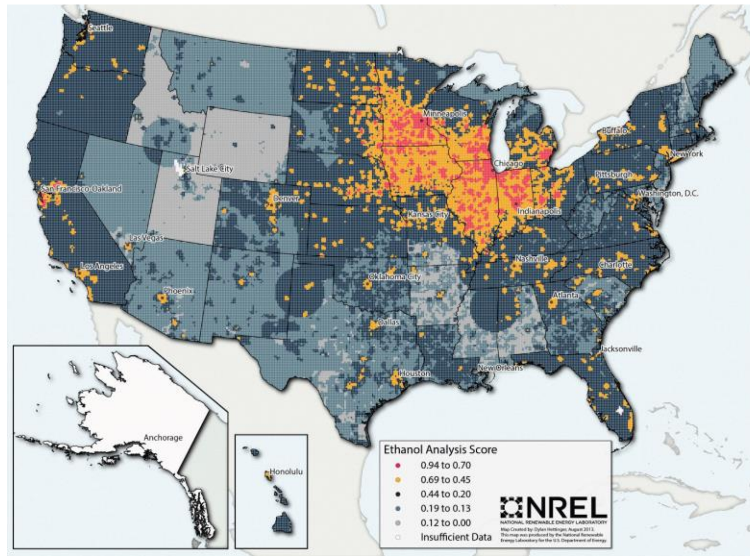


Fig 2: Active ethanol markets. Red is the most active, with dark blue and grey being the least active. Courtesy of NREL.

While mid-level blends were outside the scope of NREL's geographical market analysis, they are the focus of an upcoming analysis. Consumer perception of ethanol as a superior fuel could play a significant factor in the marketing success of a high octane mid-level ethanol blend.

## Lifecycle Greenhouse Gas Accounting

Congress mandated lifecycle greenhouse gas reduction targets for renewable fuels and instructed EPA to oversee this process. A fuel pathway process certifies whether a feedstock or production process qualifies as renewable. This 'well-to-wheels' assessment considers cumulative GHG emissions derived from each step of fuel production, and is commonly referred to as a lifecycle analysis. According to the *Clean Air Act*, lifecycle greenhouse gas emissions are defined as the "aggregate quantity of greenhouse gas emissions … including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential."[11]

Various components of lifecycle greenhouse gas emissions are calculated by EPA for the Renewable Fuel Standard using several models, including the "Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model" (known as GREET) developed by scientists at Argonne National Laboratory. GREET is a comprehensive modelling tool of lifecycle emissions. To estimate GHG emissions from changing land use, GREET combines land use change modelling results from Purdue's Global Trade Analysis Project (GTAP) model with soil organic carbon data and carbon emissions from land use. GREET also incorporates updated production improvements at bio-refineries, including increased co-products, reductions in energy and water use, and increased yields—both at bio-refineries and in fields.[12] Researchers from ANL have calculated that corn ethanol may reduce lifecycle GHGs relative to gasoline by 19 to 48 percent, and cellulosic ethanol sourced from corn stover may reduce lifecycle GHGs by 90 to 103 percent relative to gasoline.[13]

Using GREET, scientists from ANL estimate that a nation-wide E25 blend with a 5 percent fuel economy gain could reduce the GHG intensity of the transportation sector between 5 to 9 percent, a significant reduction. A mid-level E40 blend sourced from cellulosic ethanol could attain up to 30 percent GHG reductions.

## Conclusions

The retail fuel market is evolving. Retailers, carmakers, and regulators are now examining the potential economic, environmental, and engine benefits of high octane, mid-level ethanol blends. While there are numerous details to consider for individual station owners, including infrastructure compatibility and price, 17.4 million FlexFuel Vehicles that can use a high-octane, mid-level ethanol blend are already on the road today. Additionally, 80 percent of the existing fleet is able to use an E15 blend. Using higher blends of ethanol as a high octane fuel can achieve significant CO2 reductions in the near-term, helping the United States meet multiple policy objectives.

Going forward, marrying engine design and fuel quality has great potential to significantly increase the engine efficiency of the future fleet. Recognizing the efficiency limitations of the current transportation fleet, DOE is investigating future fuel and engine design in their Co-Optimization of Fuels and Engines (Optima) Initiative, a collaborative effort between fuel producers (of both ethanol and gasoline), the automotive industry and DOE. Optima's goal is to reduce per-vehicle petroleum consumption by 30 percent by 2030 using a combination of improved fuels, growth of the bio-economy, and alternative vehicle technologies. If achieved, this could reduce petroleum consumption by 4.5 billion barrels and save consumers up to $50 billion.

This fact sheet is available electronically (with hyperlinks and endnotes) at *www.eesi.org/papers*.

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