# Fuel Ethanol:
## The Future of Clean Octane, Today

Prepared for the
**U.S. Grains Council** by the
**Illinois Corn Marketing Board**

# EXECUTIVE SUMMARY

Ethanol has a very successful history as a motor fuel and the outlook for its future use is promising. Ethanol has significant value as a motor fuel due to its high octane rating. Whether improving air quality, extending the current fuel supply, creating domestic energy production or arresting global warming, ethanol is a successful answer to all of these complex problems.

Delivering a positive energy balance is only one aspect of the environmental goals global policy makers hoped that a growing fuel ethanol industry would deliver. Also vital to policymakers was that the production and use of fuel ethanol deliver clear reductions in greenhouse gas emissions (GHG) when compared to fossil fuels. The U.S. Department of Agriculture prepared a recent life cycle assessment of corn ethanol that reflected the latest research and production efficiencies leading to a 43% reduction in emissions for ethanol when compared to the baseline gasoline.

For a long time, tetraethyl lead was used to increase the octane rating of motor vehicle fuels. It was phased out beginning in the late 1970s because it was discovered that emissions from the combustion of leaded gas increased atmospheric lead, a highly toxic compound with serious public health implications. Today, the octane in gasoline is increased using a blend of hydrocarbon aromatics and ethanol. Ethanol provides a safe alternative to increased octane in liquid fuel inventories without degrading ambient air quality.

**Ethanol provides many advantages to fuel today including:**

**Octane enhancement**
Ethanol is a high octane fuel component available today around the world.

**Environmental benefits**
Ethanol reduces greenhouse gas emissions by anywhere from 34% up to and even surpassing 100% depending upon the feedstock and production methods used.

**Health benefits**
Ethanol reduces the levels of aromatics in gasoline blends which are the primary component of harmful tailpipe emissions.

**Fuel source diversity**
Ethanol usage diversifies fuel supply and decreases dependence on the handful of oil-producing nations in the world.

**Fuel prices**
Ethanol as a low-cost fuel competes with gasoline, generating downward pressure on prices. Additionally, by adding volume to the fuel supply the supply/demand scenario becomes more favorable for the consumer.

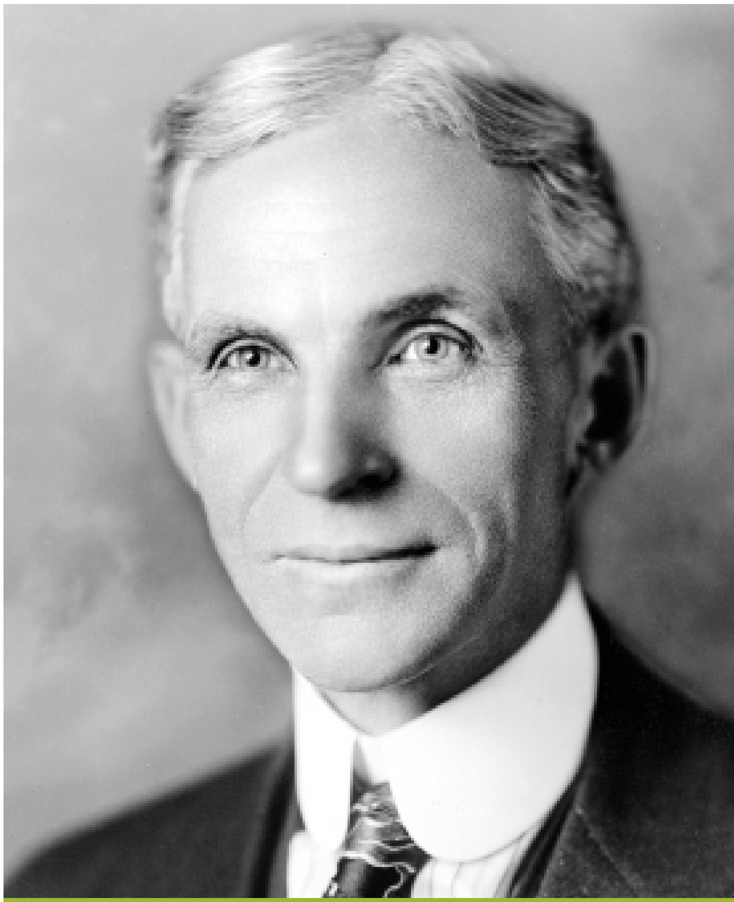
# FUEL ETHANOL: THE FUTURE OF CLEAN OCTANE, TODAY

Nature's resources have enabled humans to thrive and prosper. Whether feeding humans, horse, oxen or other animals, plants have provided them the energy to walk, run and ride since time began.

It is only in the last century that we have looked below-ground for our transportation needs. The age of oil created easy, portable energy to fuel automobiles that helped push our society to new heights. But there were costs that came with using resources outside of the natural cycle. Environmental consequences are evident in the air we breathe and rising temperatures around the globe.

The fuel of today – ethanol – is not a new idea. Henry Ford had a vision in the early 20th century that in effect, took humanity back to its roots. We could meet our needs as we always had, through the resources available above the ground. Ethanol, he said, was the "fuel of the future."

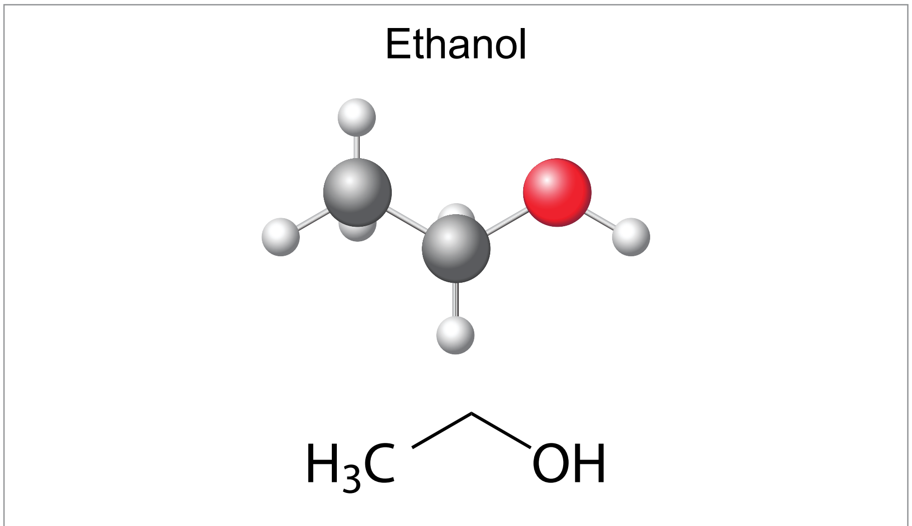
**The future is today.**



Portrait of Henry Ford (ca. 1919)

# WHAT IS ETHANOL?

Ethanol is an alcohol with specific properties that make it the best molecule in the alcohol family to include in fuel blends. It is a clear, colorless liquid made by fermenting plant matter. It is a flammable liquid with many qualities that make it well suited for use in internal combustion engines. Ethanol has a very successful history as a motor fuel and the outlook for its future use is promising. Ethanol has significant value as a motor fuel due to its high octane rating.




An illustrated diagram of an ethanol molecule.

Most ethanol today is made from corn starch, sugar cane or sorghum; however, virtually any plant matter can be made into ethanol. Advances in technology in recent years have enabled the first “cellulosic” ethanol plants to begin producing ethanol. Cellulose is the most abundant organic molecule on earth; it is what gives a plant its structure. Grasses, wood waste, crop residue and other forms of biomass hold great potential in growing ethanol use around the world.

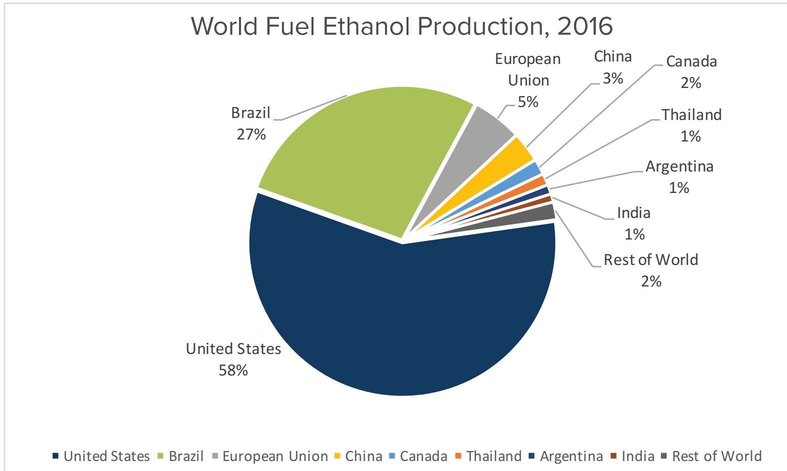
Ethanol has the same chemical formula (CH3CH2OH) regardless of its source material. Sugarcane ethanol, corn ethanol and cellulosic ethanol are all the same fuel at the end of the process. Whether improving air quality, extending the current fuel supply, creating domestic energy production or arresting global warming, ethanol is a successful answer to all of these complex problems.

# WHERE IS ETHANOL PRODUCED?

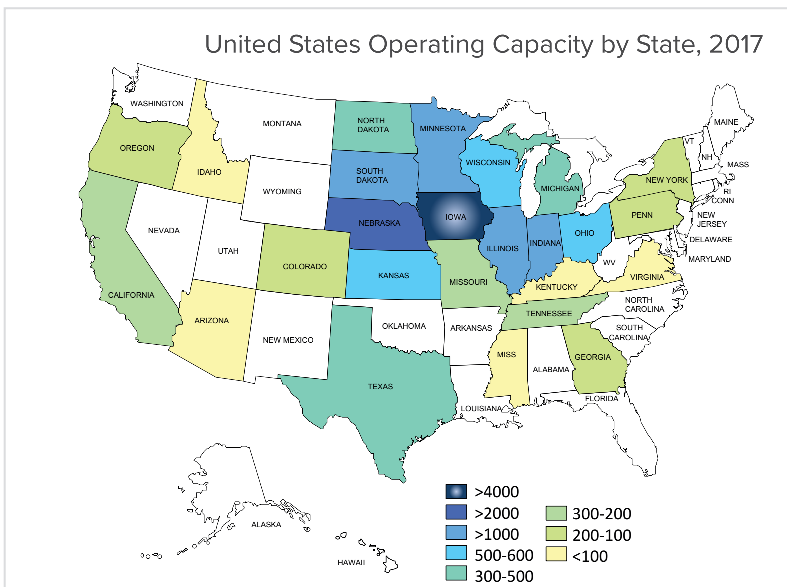
The majority of ethanol produced (approximately 85%) today comes from the United States and Brazil. Europe, China and Canada have developed robust ethanol industries as well. Many countries throughout Latin America and Asia have begun to develop their own ethanol production infrastructure.

In the United States, ethanol production is primarily concentrated in the Midwest. The top 10 ethanol producing states, in order, are Iowa, Nebraska, Illinois, Minnesota, Indiana, South Dakota, Kansas, Wisconsin, Ohio and North Dakota. Ethanol produced in these areas is primarily made from corn starch due to the abundance of corn produced there each year.

In Brazil, most of the ethanol production is concentrated in the south central and northeast regions of the country. Brazil takes advantage of its robust sugarcane production by requiring the use of ethanol blended vehicle fuels. The government regularly adjusts its ethanol production quotas on a number of factors but primarily on whether it is more profitable to produce sugar or ethanol.



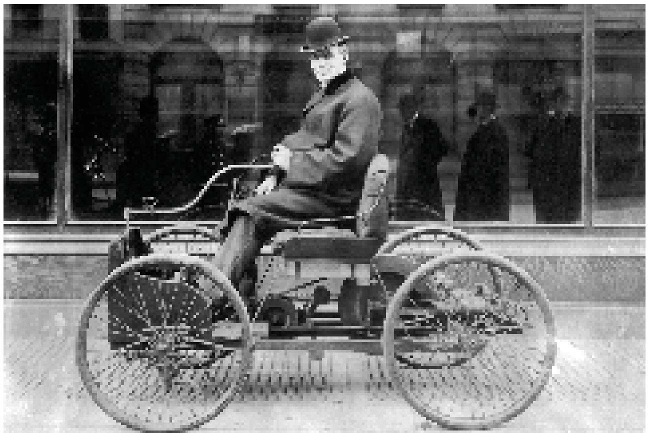

Data Source: RFA. "World Fuel Ethanol Production." Retrieved, April 2017. http://www.ethanolrfa.org/resources/industry/statistics/#1454099103927-61e598f7-7643




Data Source: USDA. "U.S. Bioenergy Statistics." Retrieved, April 2017. https:www.ers.usda.gov/data-products/us-bioenergy-statistics.aspx

With the first cellulosic ethanol plants now coming online, there is potential for new production pathways to ethanol for virtually every nation in the world. New sources of biomass, such as corn stover, wheat straw, rice straw, wood waste, and switchgrass, and energy crops, such as miscanthus, will provide new avenues for ethanol in the future.

# HISTORY



Henry Ford sits in his first automobile, the Ford Quadricycle, in 1896.

Ethanol, as a fuel, is as old as the modern engine itself. In 1826, Samuel Morey developed an engine that ran on ethanol and turpentine. Later, in 1860, Nicholas Otto, the father of the modern internal combustion engine, used ethanol as a fuel in one of his engines. Henry Ford's first automobile, the quadricycle, ran on pure ethanol. Throughout the 20th century, ethanol as a fuel grew primarily in times of fuel shortage, most notably during World War I and World War II.

Brazil introduced ethanol as a motor fuel around 1920; however, countrywide use accelerated in the 1970s. Today, the two motor fuels for Brazilian consumers are petrol with 18-27% ethanol or a hydrous ethanol fuel. The history of ethanol production in the United States saw many highs and lows before gaining widespread use in the 2000s.

But it wasn't until the 1970s that the first real push for ethanol production began in the United States and Brazil. A number of factors led to this. In the 1970s, governments around the world wanted to reduce reliance on crude oil from hostile countries which renewed interest in ethanol as a motor fuel. During the same time period, the detrimental health effects from the use of tetra-ethyl lead (lead) as a gasoline octane improver were exposed. Ethanol was one of the replacements for lead as an octane booster and anti-knock agent. For the United States specifically, the Organization of the Petroleum Exporting Countries (OPEC) oil embargo and subsequent oil price shocks in the 1970s led to the United States' creation of the Energy Security Act. In President Jimmy Carter's 1979 energy address to the nation, he asserted as one of his priorities, "From the products of our forests and croplands, we can produce more (ethanol), already being used to replace gasoline in several Midwestern states."

In the 1990s, a new push for ethanol production began, as evidence mounted of global warming's damaging effects from fossil fuels used for personal transportation. Public policy programs were developed to reduce the negative effects from transportation by incentivizing the development of environmentally friendly, renewable fuels like ethanol.

Thanks to these renewable energy policies, ethanol production in the U.S. has grown to nearly 15 billion gallons (over 50 billion liters) annually, as of 2017. While it still fulfills the valuable role of an oxygen enhancer, it is also being used in greater quantities driven by the steady growth of ethanol blends with 15, 20 or even 30% ethanol by volume. Ethanol use now surpasses 10% of the gasoline supply, and is set to continue growing.

# VEHICLE DESIGN

Recognizing the need to expand past the reliance on fossil fuels, automobile and engine manufacturers began designing their products to operate on a more diverse range of fuels, including ethanol. Since the 1970s, automobile and engine manufacturers have recommended the use of oxygenated in their vehicles, while specifically naming ethanol. Oxygenated gasoline contains chemical compounds that have oxygen within their chemical structure. The use of oxygenates allows for the more complete combustion of fuels, helping to reduce carbon monoxide and soot from tailpipe emissions. This recommendation appears in the manufacturer's owner's manual.

Today's vehicles are designed to operate on ethanol concentrations of no less than 10% for the most common vehicles and up to the 100% ethanol powered for flexible fuel vehicles. Flexible fuel vehicles are designed to operate on fuels with high concentrations of ethanol, high concentrations of gasoline, and all blends in between. Ethanol blended fuels provide acceptable drivability, starting, idling, acceleration and safety. A century of successful use and thousands of research programs confirm that ethanol is a wise choice as a motor fuel.

The production and sale of flexible fuel vehicles has risen steadily within Brazil since the early 2000s, and by the end of 2014, over half of the registered light duty vehicles in Brazil were flex fuel. Since 1976, the Brazilian government has mandated the inclusion of ethanol in gasoline. The inclusion rate has fluctuated between 10-27% since then, typically adjusted only during times of supply constraints. Gasoline with 10% ethanol (E10) has been in primary use in the United States since the promulgation of the Clean Air Act Amendments of 1990. Over 240 million vehicles on the road today regularly use E10 with great performance under all climates, elevations and weather conditions.

**In the U.S., there are over 240 million vehicles on the road today regularly use E10 with great performance under all climates, elevations and weather conditions.**

# FLEXIBLE FUEL VEHICLES

Ethanol debuted as the primary component in certain motor fuel blends in the early 1990s. These high-ethanol content fuel blends are restricted for use in flexible fuel vehicles, sometimes referred to as "dual-fueled vehicles" or "variable-fuel vehicles." A flexible fuel vehicle (FFV) is one that can operate on gasoline containing no ethanol, fuel blends of 85% by volume denatured fuel ethanol, or any combination of the two. The Ford Model T, first produced in 1908, was one of the first flexible fuel vehicles made.

Flexible fuel vehicles are very popular in Brazil and in the United States. Today, 16 automakers offer more than 242 different models of flexible fuel vehicles accounting for 68% of the Brazilian motor fleet. There are nearly 20 million flexible fuel vehicles on U.S. roads at present.

# VEHICLE EMISSIONS

The largest contributor to carbon monoxide emissions is from transportation sources. Possibly the most significant air quality benefit from ethanol is the significant reduction of carbon monoxide from vehicle exhaust emissions. Carbon monoxide is the precursor to ground-level ozone formation leading to smog. Ethanol is also a powerful diluent for the toxic compounds in gasoline such as benzene. The addition of ethanol not only reduces the toxic compounds by reducing their emission but also decreases engine combustion chamber deposits caused by the same toxic, aromatic compounds. Although there is vehicle to vehicle variability on nitrous oxide emissions with ethanol fuel blends, the overall effect is neutral. In many cases, emissions reductions are the direct result of ethanol's clean-burning properties. The use of ethanol in older vehicles results in greater emissions reductions so countries with higher percentages of vehicles from older model years would experience accelerated emissions benefits when compared to countries with a younger overall vehicle fleet.

Air-quality is greatly improved as a result of the addition of ethanol to gasoline. The ethanol molecule contains 33% oxygen by mass. Fuel oxygen improves vehicle emissions through more complete combustion and the reduction of gasoline aromatics. Engine exhaust emissions, particulate matter, carbon monoxide, toxics, ozone and greenhouse gases are reduced when ethanol is added in meaningful quantities. Another type of vehicle emissions, evaporative emissions, are also controlled to improve air quality. This category of emissions has shown dramatic reduction in overall emissions, including when the engine uses ethanol fuel blends. The largest improvement in vehicle evaporative emissions are due to the automobile industry adoption of new control technology and improved materials of construction for this equipment.

# FUEL ECONOMY

Many drivers routinely keep track of their vehicle's "gas mileage", known officially as fuel economy; however, determining a precise calculation for miles traveled per gallon is a bit more complex. Factors that affect a vehicle's fuel economy can include engine state of operation, excess cargo weight, driving habits and gasoline composition. Many times these factors have a significant impact on the fuel economy; these factors have much more impact than the fuel composition itself. "Stepping on the gas" or driving aggressively has the most significant impact on a vehicle's fuel economy. Keeping a vehicle in top operating condition, with properly inflated tires, is a simple task consumers can practice to ensure efficient operation.

Many factors affect fuel economy:

- Aggressive driving can lower gas mileage by 33% on highway and 5% around town.
- Using electrical accessories (for example air conditioner) reduces mileage 5-25%.
- Using oxygenated fuels or reformulated gasoline can cause a small decrease of between 1-2%. This is not a certainty and some research shows that the use of oxygenated fuels increases engine performance to the extent that mileage loss is completely eliminated.

Newer model vehicles may actually calculate fuel economy instantaneously, reporting fuel economy in miles per gallon (or kilometers per liter). The numerous sensors on modern vehicles detecting loose gas caps, low tire pressure, and proper state of operation of the engine all assist in consumers achieving improved fuel economy.

While it is true that ethanol contains fewer British Thermal Units (BTU) per gallon than gasoline; it is important to remember that gasoline's BTU value fluctuates seasonally. These mileage reductions can vary from vehicle to vehicle, with some seeing a greater reduction and some seeing little to no impact on mileage due to ethanol use.

## Common Reductions in Vehicle Fuel Economy

Loss in MPG (miles per gallon)

# FUTURE TRENDS

**The U.S. Department of Energy has concluded that fuels with between 20-40% ethanol would deliver the greatest potential emissions and greenhouse gas reductions while maintaining efficiency requirements when combusted inside engines designed to optimize such fuels.**

Worldwide ethanol use will grow not only due to octane shortages but also with greenhouse gas reduction initiatives. It is expected that higher concentrations of ethanol will be used in the future. Research of late in Brazil, Germany, and the United States has focused on gasoline blends above 10 percent ethanol. Many automakers see great potential in "mid-level" blends of ethanol. Future engines could be designed to better take advantage of ethanol's high-octane benefits. The U.S. Department of Energy, working in concert with national laboratories, has concluded that fuels with between 20-40% ethanol would deliver the greatest potential emissions and greenhouse gas reductions while maintaining efficiency requirements when combusted inside engines designed to optimize such fuels.

Using E30 in an engine designed to take advantage of its improved octane would provide "ridiculous power and good fuel economy," said a senior engineer for U.S. fuels policy at Mercedes-Benz.

A 2012 study by engineers at Ford Motor Company noted:

"The high octane rating of ethanol could be used in a mid-level ethanol blend to increase the minimum octane number … of regular-grade gasoline. Higher [octane] would enable greater thermal efficiency in future engines through higher compression ratio and/or more aggressive turbocharging and downsizing, and in current engines on the road today through more aggressive spark timing under some driving conditions."

Ford Motor Company further predicted, "It appears that substantial societal benefits may be associated with capitalizing on the inherent high octane rating of ethanol in future higher octane number ethanol-gasoline blends."

As the world continues to explore opportunities to replace fossil fuels, ethanol's presence will certainly grow. It is the most prevalent renewable liquid transportation fuel in the market today, and it has great potential for future engines designed to take advantage of its unique benefits.

# A POSITIVE ENERGY BALANCE AND REDUCED GREENHOUSE GAS EMISSIONS

Many research studies confirm, it has been made clear that the use of ethanol as a transportation fuel delivers real environmental benefits including both a positive energy balance and reductions in greenhouse gas emissions. Both of these outcomes were fundamental goals of governmental policies that gave rise to the ethanol industry. Research conducted by university, government and private institutions confirms not only that the use of ethanol has achieved the goals originally set for it, but also surpassed them. As ethanol production technology matures, the trajectory is set for even further environmental benefits and reduced use of fossil inputs within the transportation sector.

# ENERGY BALANCE

Beginning in the late 1970s, extensive research was conducted regarding the energy balance of ethanol. Policy makers wanted assurance that the production of ethanol delivered more energy than was required for its manufacture.

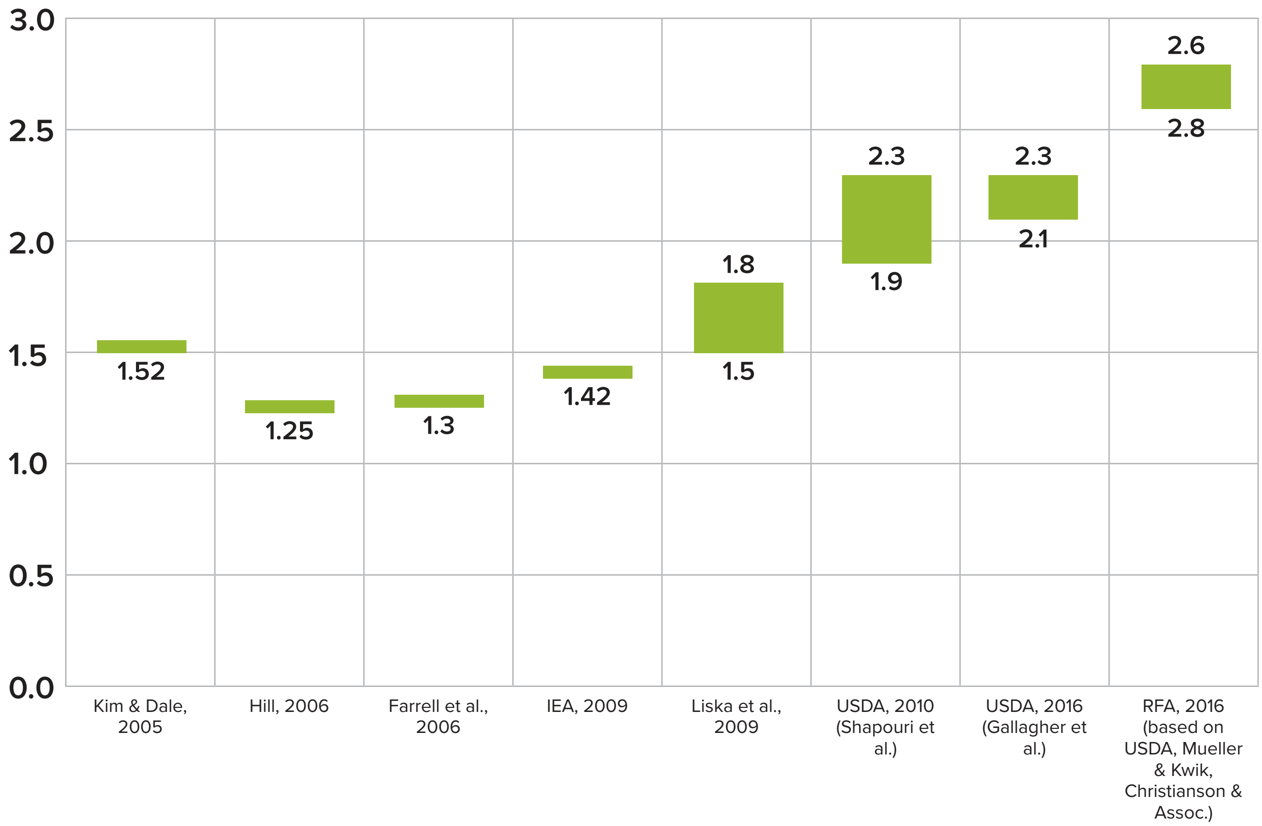
Numerous studies have been conducted by government labs, university researchers and trade associations and a significant body of work and methodologies are now well established. This work continues today. Energy balance is the amount of energy used to produce ethanol throughout its entire supply chain, including crop production, grain transportation, ethanol production and downstream distribution minus any fossil fuel inputs found along that same production and supply chain. In this scientific analysis, any result greater than 1 indicated that more energy in the form of ethanol was produced than the fossil fuel required to make it. Any result below 1 indicates that more fossil fuel energy was required to manufacture the ethanol than it delivered.

Studies conducted from 2005 to 2010 arrived at energy balance scores between 1.25 and 1.52. Even in the industry's nascent stages, ethanol was delivering a positive energy balance. Furthermore, ongoing research in energy balance began to indicate that both the corn growing and ethanol production industries were becoming more efficient and energy balance numbers began to rise reflecting those efficiency gains. In 2009, a study published in the *Journal of Industrial Ecology* found that energy balances for ethanol had improved to between 1.9 and 2.3 (Shapouri, *et al.*) The range in energy balances reflects subtle differences in production methodologies, varying thermal energy sources and transportation distances for feedstock and final product. The 2015 U.S. Department of Agriculture study (Gallagher, *et al.*) confirmed the continued improvement in energy efficiency in ethanol production since 2010, with the greatest number of ethanol production facilities operating with a wide variation of biorefinery configurations. The most recent analysis confirms the path of continued improvement in energy contribution with a positive energy output ratio of 2.6- 2.8.

The reality is the energy balance of ethanol is always positive. There will always be slight variations from production facility to production facility. What is clear is that ethanol made from corn or sugar cane delivers a significantly positive return on fossil fuel inputs. Unlike fossil fuels, renewable fuels like ethanol are improving the energy balance equation.

**Ethanol: Renewable Energy has a Positive Energy Balance**

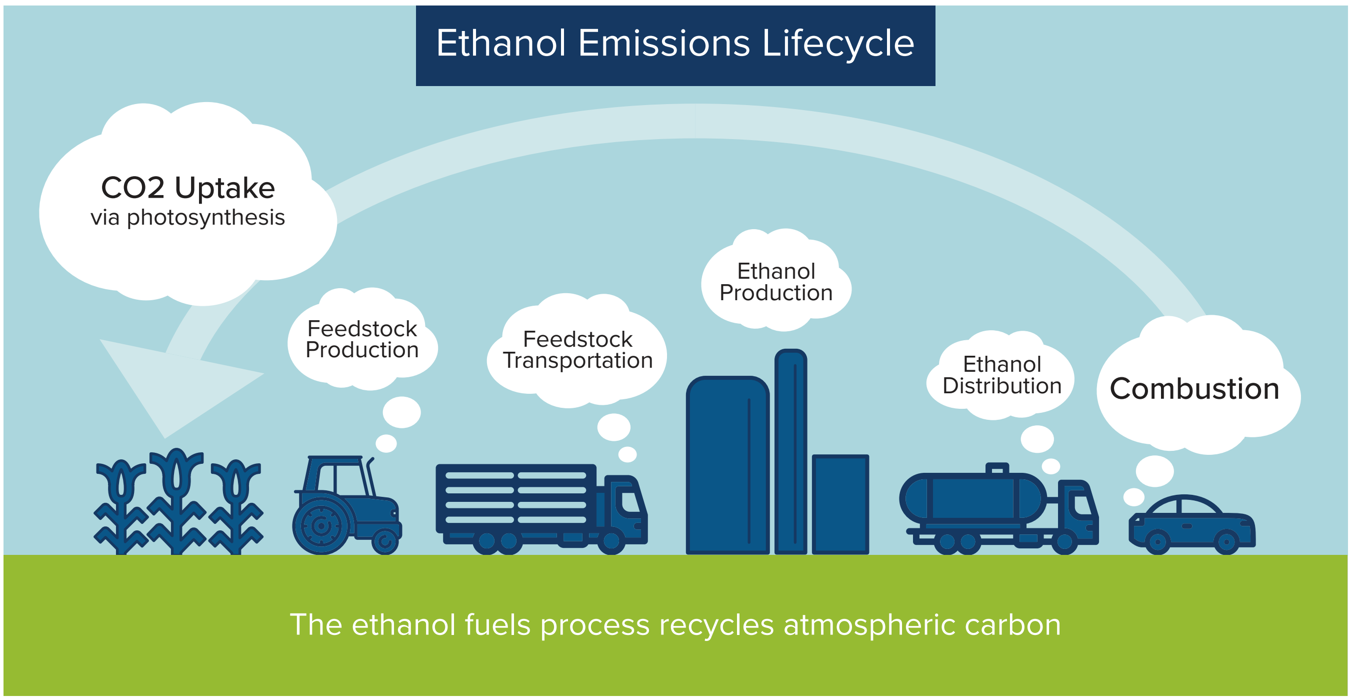
Dry Mill Corn Ethanol Avg. Energy Balance Ratio Estimates, 2005-2016




Data Source: RFA. "Re-examining Corn Ethanol's Energy Balance Ratio." Retrieved, May 2017. http://www.ethanolrfa.org/wp-content/uploads/2016/03/Re-examining-Corn-Ethanols-Energy-Balance.pdf

# GREENHOUSE GAS EMISSIONS

Delivering a positive energy balance is only one aspect of the environmental goals global policy makers hoped that a growing fuel ethanol industry would deliver. Also vital to policymakers was that the production and use of fuel ethanol deliver clear reductions in greenhouse gas emissions (GHG) when compared to fossil fuels. This question generated considerable debate and the need for a comprehensive, peer-reviewed fuel lifecycle analysis was quickly realized.




In 1996, Dr. Michael Wang, a senior scientist at the U.S. Department of Energy's Argonne National Laboratory developed a comprehensive life-cycle model to evaluate the emissions and energy impacts of conventional and emerging transportation fuels. The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model has since become the most widely accepted method of calculating the environmental impact of transportation fuels in the world. The GREET model is capable of analyzing the energy use in over 100 different fuel pathways including conventional petroleum fuels, biofuels, hydrogen and electricity.

Again and again, even when accounting for the highly controversial land use change burden, the GREET model indicated that ethanol delivered real environmental benefits when compared to fossil fuel counterparts – no matter the renewable feedstock used to produce the ethanol. The key to understanding the environmental advantages delivered by ethanol is to remember that one of the energy inputs in ethanol production, whether made from cornstarch, corn stover or sugarcane is solar energy. This renewable and environmentally benign energy source is the foundation of the environmental benefits of corn ethanol and the advanced biofuels that will follow. Corn, sugarcane and other crop and biomass inputs used for the manufacture of ethanol convert solar energy into starches that are later fermented into fuel ethanol.

Petroleum-based fuel is growing more energy-intensive and inflicting a greater impact on the environment with sources, such as tar sands, and techniques, such as hydraulic fracturing also known as fracking. In contrast to that trend, the environmental benefits of ethanol continue to grow. In an August, 2016 study Steffen Mueller, principal economist with the University of Illinois at Chicago Energy Resources Center asserted:

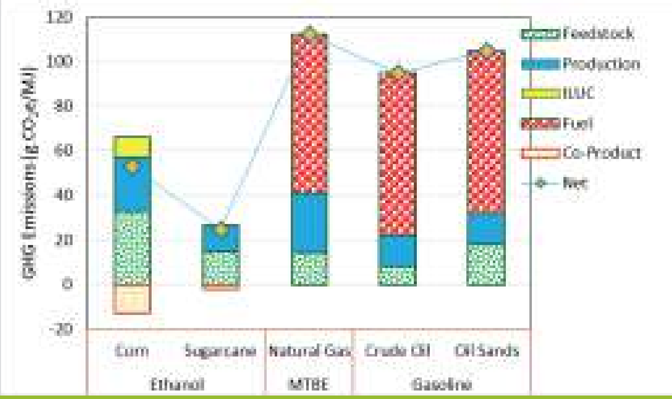
"The ongoing efficiency improvements along the corn ethanol production pathway have resulted in a continued reduction of ethanol's greenhouse gas life cycle emissions and are widening its environmental advantage over petroleum."

**The U.S. Department of Agriculture prepared a recent life cycle assessment of corn ethanol that reflected the latest research and production efficiencies leading to a 43% reduction in emissions for ethanol when compared to the baseline gasoline.**

While a significant amount of ethanol produced in the U.S. meets the 35% GHG reduction threshold, new developments mean that anywhere from 25-40% of U.S.-produced corn ethanol can meet the more rigorous 50% GHG reduction threshold required by a number of foreign nations.

Recently, a study was commissioned by the U.S. Department of Agriculture to prepare a life cycle assessment of corn ethanol that reflected the latest research in land use changes and the efficiencies of both farming practices and ethanol production as well as the production of key agricultural inputs, including nitrogen fertilizer. The study found that while fuel production, land use changes and nitrogen fertilizer continue to be the largest contributors to the carbon intensity of corn ethanol, substantial changes and efficiencies have been realized in each. The results of the study indicated that a review of the latest science and farmer behavior demonstrates that corn ethanol provide a 43% reduction in emissions when compared to the 2005 baseline calculated for gasoline.

Every ethanol production facility employs slightly different technologies, energy sources and menus of co-products, which accounts for the varied GHG savings from corn ethanol when comparing one plant to another. History has shown the GHG impacts of corn ethanol will continue to decrease as even more technological advances are realized. Finally, next generation biofuels show even more GHG reduction promise and the GREET model shows a nearly 90% reduction in GHG emissions is possible. Ethanol, whether produced from corn or sugarcane, provides significant greenhouse gas emission reductions when compared to fuels made from petroleum.




Data Source: GREET1_2016, Calculations by Life Cycle Associates.

The newest research highlights a number of areas that take some corn ethanol production beyond a 50% reduction in greenhouse gas emissions.

**Corn oil separation:** By separating corn oil during the production process, ethanol producers are providing a new feedstock for even more biofuel production, which offsets more petroleum use and thus lowers the greenhouse gas impact of ethanol. In 2016, corn oil from ethanol plants accounted for 14% of all feedstock for biomass-based diesel fuel.

**Energy efficiency improvements and enzymes in seed traits:** Ongoing energy efficiency improvements in ethanol plants have created new GHG savings. Additionally some ethanol producers are now getting strains of corn that have enzymes built into the corn trait. These varieties decrease the energy needed to produce ethanol and further lower the GHG impact of corn ethanol.

**CO2 recovery:** Many ethanol plants capture and liquefy CO2 and sell it into the food and beverage industry and other markets. This carbon-sequestration method from ethanol producers now accounts for about 40% of the North American market for CO2.

**Wet distiller's grains:** Distiller's grains, a highly nutritious animal feed, are often dried for longevity and transportation considerations. Ethanol plants located near feedlots can sell wet distillers grains', thus eliminating the energy needed to dry the product.

**Anaerobic digestion:** Distillers grains fermentation byproducts can be fed into an anaerobic digester. A number of U.S. ethanol plants use this technology to produce biogas and further decrease their need for fossil energy.

# CO-PRODUCTS

The full environmental, energy and economic contributions of ethanol cannot be completely understood without an examination of the co-products also produced during its manufacture. The production of ethanol from corn requires only the starch component or fraction of the corn kernel. The remaining fractions are converted into other valuable products which dramatically increase the overall energy, environmental benefit and overall economic stability of the ethanol industry.

## Distiller's Grains and Distiller's Grains with Solubles

Ethanol made from corn requires only the starch component of the corn, which represents about 70% of the kernel. The other 30% contains proteins, fats and fibers that hold incredible value as feed products for cattle, swine and poultry markets. These products are produced alongside ethanol and are known as distiller's dried grains (DDG) or distiller's dried grains with solubles (DDGS), corn fiber, corn distillers oil and zein proteins, depending upon their respective production methodologies.

As corn enters an ethanol production facility, a hammer mill breaks each corn kernel into many fragments. This exposes the starch portion of the kernel that is converted into ethanol via fermentation. The remaining components of the corn kernel pass through the fermentation process unaffected.

These non-fermentable components are separated from the water used in the fermentation process using centrifuges and evaporators. For DDG and DDGS, a dryer is then used to dry the material down to the desired moisture levels. The decided-upon moisture levels in DDG and DDGs are driven by the distance the products will have to travel to reach their final market. Distiller's grains with between 65-70% moisture are known as wet distiller's grains and must be sold within a few days of manufacture to users within the immediate vicinity of the production facility. Distiller's grains dried to 50-55% moisture can last several weeks, allowing for longer transit times to final markets. Distillers grains dried to 10-12% moisture can be stored for long periods and as a result can be traded globally.

From a 56-pound bushel of corn, approximately 17 pounds is recovered as distiller's grains and is sold into local and global feed markets. It is critical to acknowledge that this sizeable percentage of the corn kernel used in the manufacturing process would reenter the marketplace as a high-value feed product. Furthermore, because of the unique nutritional composition of distiller's grains, animal feeding studies have shown that one ton of distiller's grains displaces on average 1.22 tons of corn and soybean meal (Hoffman and Baker, 2011). The result is that 38% of the weight of corn entering an ethanol production facility returns to the market as a high protein distiller's grains feed product.

Today, distiller's grains are one of the most important feed products in the world. The U.S. ethanol industry produced nearly 40 million tons of high quality animal feed. As production volumes rose along with the expansion of the ethanol industry, so too have inclusion rates. In 2010-2011 distiller's grains eclipsed soybean meal as the number two most common feed product consumed domestically.

The global marketplace has shown an incredible appetite for this high-value product and export volumes have hovered around 10 million tons for the past five years, or 25% of the total volume produced. China, Mexico, Vietnam and South Korea are the largest buyers of distiller's grains.

## One bushel of corn provides:

**2.8**
gallons of fuel ethanol

**17.5**
lbs of DDGS*

**1.5**
lbs of corn oil**

*In dry-grind ethanol process
**In wet-mill ethanol process

## Corn Oil

Approximately 4% of corn by weight is oil. Corn oil, like protein and fiber, is not a fermentable component of the corn kernel. Until the mid-2000s this component was simply captured with the protein and fiber and was included in the distiller's grains. Between 2005 and 2007, ethanol producers worked in earnest to isolate corn oil from the distiller's grains and this product is referred to as corn distiller's oil. This product has a value in feed markets and as a feedstock for biodiesel production. Corn distiller's oil, from the ethanol production process, made up 14% of the principal feedstock in U.S.biodiesel production.

The extraction and downstream use of corn distillers oil is an illustration of the continued innovation driving up the energy balance of fuel ethanol production. The extraction and downstream conversion of distiller's corn oil into biodiesel increases the energy output from a fuel ethanol facility by 1,440 BTU/gal, or roughly a 2% increase in the plant's total energy output.

## Continued Innovation

As the ethanol industry advances, competition continues to spur investment in innovation. Initially the ethanol industry produced two principal products, ethanol and distiller's grains. Once optimized, corn distiller's oil extraction became commonplace within the industry and now nearly 90% of the U.S. corn ethanol facilities extract and sell corn distiller's oil.

Corn fiber is the next corn kernel component being targeted for isolation and further refining. Like corn distiller's oil before it, corn fiber streams are currently a part of the distiller's grain product stream. Within the past four years, the isolation and fermentation of the cellulosic fibers in a corn kernel has progressed from a promising laboratory-scale concept to a pilot scale technology being actively marketed to existing producers. Another promising product from the ethanol production process is the extraction of zein proteins. These proteins have both food and industrial uses, including use as a polymer to make 100% biodegradable packaging and films.

As innovation pushes forward, the overall environmental contributions of ethanol production and use are on a path of continual improvement.

# FUEL QUALITY

If ethanol is to deliver on its incredible promise of environmental benefits, it must first deliver the technical and environmental requirements already in place for liquid fuels. A large body of evidence has been generated since its introduction into the marketplace of the fuel's performance and emissions metrics. Ethanol is a transportation fuel with a robust quality standards program already in place, a volatility profile that fits inside the requirements of today's motor fuels and the ability to deliver vital octane.

## ASTM International

In order to ensure that motor fuels continue to meet the needs for safe and efficient use, standards have been developed that allow every party involved in their production and use to fully understand a given fuel's physical, mechanical, thermal and chemical properties. The most widely recognized fuel standards have been developed by ASTM International, an international body that publishes consensus-based technical standards for a wide variety of materials. Motor fuels, including ethanol, are among over 12,000 ASTM standards developed and recognized around the world.

As the production and use of ethanol at varying levels of inclusion increased, international standards including those developed by ASTM International have evolved to include all levels of ethanol from 1-83% by volume.

The earliest work on developing a standard that recognized fuel ethanol's inclusion into the gasoline began in 1978.

The first ASTM standard developed specifically for ethanol, D 4806 – Specification for Denatured Fuel Ethanol for Blending with Gasolines for Use as Automotive Spark-Ignition Engine Fuels, was developed in 1984 and approved in 1988. This specification was intended to provide a standard for anhydrous denatured fuel ethanol intended to be blended with gasoline at volumes up to 10%. This standard establishes performance requirements on ethanol content, methanol content, solvent-washed gum, water content, denaturants, inorganic chloride, copper, acidity, pH, sulfur and sulfates.

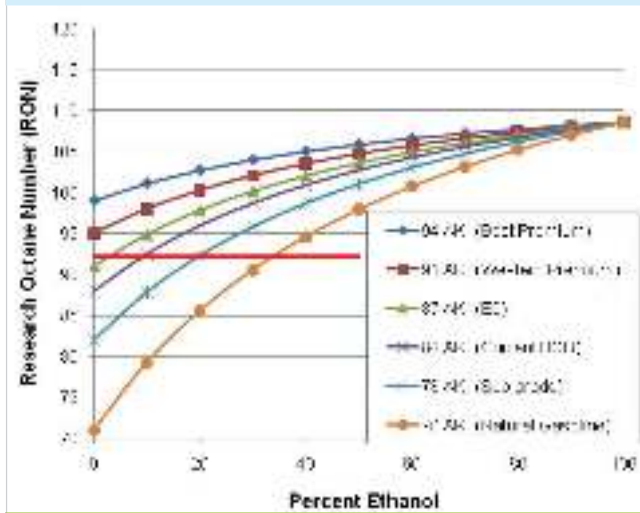
While Specification D4806 provided sufficient guidance on fuel ethanol's use as a blend-stock, it failed to provide adequate guidance for fuels with much higher percentages of ethanol. As vehicles specifically designed to utilize these higher ethanol blends entered the marketplace, the need for a new fuel standard was determined. In 1993, the National Conference on Weights and Measures solicited a new standard for from ASTM for these majority-ethanol fuels. Specification D5798 Standard Specification for Ethanol Fuel Blends for Flexible fuel Automotive Spark Engines was published in 1996.

Together D4806, D5798 and D7794 provide robust fuel standard guidance for motor fuels with a broad range of ethanol inclusion. ASTM International's standards, while voluntary are cited around in the world in fuel contracts, regulations and laws.

# Properties

## *Octane*

**Ethanol Increases Octane**




Data Source: Jones, C.M. General Motors, National Ethanol Conference, 2012.

For spark-ignition engines to operate properly the fuel in an engine's cylinders must be ignited by the spark plug and not spontaneously because of compression. Premature combustion, commonly referred to as "knock" greatly reduces the efficiency of an engine and can cause engine damage. To prevent knock, additives are introduced into the fuel to increase that fuel's octane rating, a measure of the fuel's ability to resist premature ignition.

For a long time, tetraethyl lead was used to increase the octane rating of motor vehicle fuels. It was phased out beginning in the late 1970s because it was discovered that emissions from the combustion of leaded gas increased atmospheric lead, a highly toxic compound with serious public health implications. Today, the octane in gasoline is increased using a blend of hydrocarbon aromatics and ethanol. Increasing attention is being paid to the toxicity of hydrocarbon aromatics including known carcinogens like benzene, toluene and xylene and their impact on air quality. The use of these aromatics is capped by law in the United States and the increased use of ethanol provides an alternative to increase octane ratings while avoiding the addition of these known carcinogens.

Finally, a promising pathway to greater overall engine efficiency is to build higher compression engines which can harness the advantages offered by fuels with even higher octane levels. These higher compression engines can create more power using less fuel, thereby increasing the overall fuel efficiency of the light duty vehicle fleet, a key component of most greenhouse gas reduction strategies throughout the world. These efficiency gains cannot come at the expense of ambient air quality. Ethanol provides a safe alternative to increased octane in liquid fuel inventories without degrading ambient air quality.

## *Sulfur*

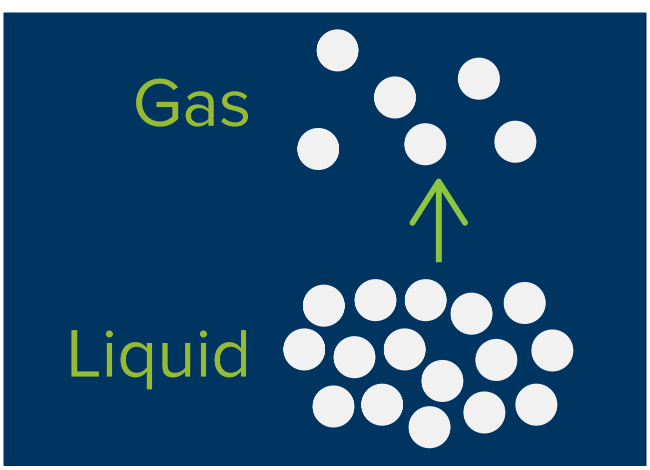
Among the most successful regulations with regard to air quality has been the aggressive control of sulfur in transportation fuels. Sulfur, which occurs naturally in crude oil kills the catalyst in the catalytic converters of automobiles designed to convert harmful emissions like nitrogen oxide and carbon monoxide into more benign gases like nitrogen, oxygen and carbon dioxide.

In 2000, the U.S. Environmental Protection Agency introduced the Tier 2 Gasoline Sulfur program limiting the sulfur content of gasoline blends to 30 ppm, preserving catalysts inside the emissions control systems of vehicles and reducing emissions up to 95% when compared to earlier vehicle models not able to deploy these systems because of the sulfur found in gasoline. In January 2017, the EPA further reduced sulfur content in gasoline to 10 ppm in an effort to reduce emissions even further.

Ethanol does not contain sulfur; however, in order to comply with tax provisions, ethanol must be denatured with a hydrocarbon to render it unfit to drink. These hydrocarbons, because they are made from crude oil, do contain sulfur. Yet, because inclusion rates of denaturants are typically 2%, the sulfur introduced into fuel ethanol does not push the sulfur content of the denatured fuel above even the more stringent 10 ppm.

## *Vapor Pressure*

Reid vapor pressure (RVP) is a means of measuring the volatility of transportation fuels. Technically, RVP is a measure of the absolute vapor pressure exerted by a liquid at 100°F (37.8°C). In practice, fuel volatility must be carefully managed to balance performance requirements while also limiting emissions associated with the transfer and distribution of the fuel.

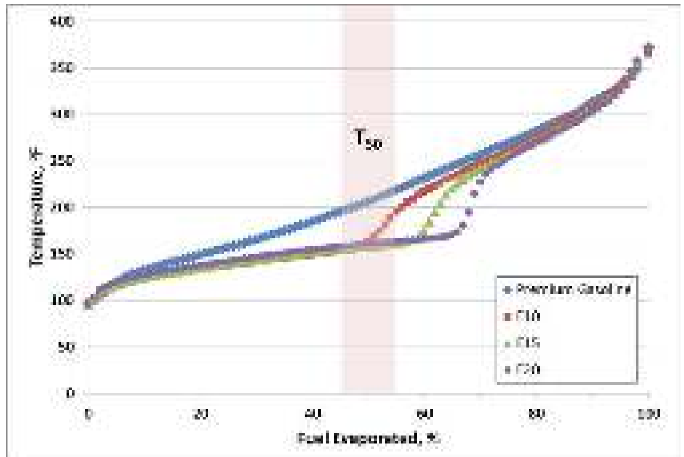



In summer months, prolonged sunlight and increased temperatures lead to the formation of ground level ozone or smog, a gas with well-documented health consequences. Smog is formed when sunlight reacts with volatile organic compounds (VOCs) emitted from a variety of sources including automobiles. For this reason, the EPA closely regulates the volatility of gasoline formulations in the months when smog is most likely to be formed. Fuels offered for sale in the summer months must have an RVP of 9.0 psi or lower.

Ethanol by itself has a lower RVP than gasoline. Yet, at lower blending ratios (<50% by volume), because of the attractive forces exerted on ethanol molecules by gasoline molecules, the RVP of the blended fuels is slightly higher than gasoline, exceeding the regulated 9.0 psi RVP during the summer ozone season by 1 pound. Because of the other emissions benefits of ethanol and the policy objective of increasing its usage in the United States, the EPA in 1992 provided a waiver that would allow fuels with 9-10% ethanol to be legally sold during the summer ozone season (June 1 – September 15).

## *Distillation*

For a transportation fuel to meet the demands of the drivers who buy it, it must deliver a number of different performance characteristics. Among the most important characteristics are a fuel's ability to help an automobile engine start, warm-up and run efficiently. Each of these outcomes require fuel components with varying levels of volatility. Components with higher volatility allow for an engine to more effectively start, while fuel components with lower volatility are available to the engine for combustion after the engine is fully warmed up.




Data Source: API MLEB report

This range of volatility is described by a distillation curve. Distillation curves have emerged as an important tool in defining a fuel's overall drivability. Ethanol's impact on the distillation curve of gas/ethanol blends have been studied at length to determine the impact of ethanol on overall drivability. While ethanol does reduce the midrange distillation curve temperatures which initially led to performance concerns; however, robust review of the available research on vehicle performance in both hot and cold vehicles shows no significant impact to vehicle performance and fuel specifications.

# DISTRIBUTION AND INFRASTRUCTURE

More than 23 billion gallons of ethanol are produced, stored, moved, blended and distributed each year in the United States and Brazil.  Additionally, ethanol is an increasingly global commodity having been exported to over 50 different countries.  The global infrastructure to store, ship and transport ethanol has expanded over the years to accommodate this global movement of ethanol.  Infrastructure required to use fuel blends with 10% ethanol may already be in place, take little to no conversion changes, or offers an opportunity to develop new transportation and storage assets.

## Storage and Handling


Fuel Pump with different ethanol blended fuels.

Ethanol is a stable product that when protected from water and ignition sources can be stored in common, readily available flammable storage vessels. In the vast majority of instances, both above-ground and underground tanks are compatible with ethanol. All steel tanks and double-walled fiberglass tanks manufactured since 1990 are E100 compatible.

Above ground storage tanks used to ethanol are typically made carbon steel or stainless steel with an internal floating roof to minimize evaporative emissions. For underground storage, most typically found at retail dispensing locations, tanks in the United States fall under the jurisdiction of the EPA's Office of Underground Storage Tanks. The EPA OUST requires that a tank system be compatible with the fuel it will store.

Ninety-five percent of the gasoline sold in the United States contains ten percent ethanol. All of the dispensing infrastructure currently in place is E10 compatible. Retailers interested in selling fuels with higher concentrations of ethanol must ensure both their above ground and below ground storage and dispensing infrastructure are ethanol compatible. The Underwriters Laboratory (UL) develops testing protocols to ensure the components of the fuel dispensing systems are compatible with the fuel's they are dispensing and there is currently a wide variety of equipment available to retailers wishing to sell higher ethanol blends.

# Transportation Modes

Every mode of transport used for the distribution of gasoline can also be brought into service to move ethanol. Truck trailers, rail tank cars, barges, ocean going vessels and ISO containers are all utilized to move ethanol.

- **Tank Trailers:** Ethanol is commonly transported in either stainless steel or aluminum tank trailers with the United Nations (UN) designations of DOT406, MC306.
- **Rail Tankcars:** Ethanol is commonly transported in carbon steel rail tank cars of the UN designation DOT111A or DOT117. Carboline Plasite liners are compatible with ethanol.
- **Barge, Ocean Going Vessels:** Ethanol is commonly transported in either lined or unlined carbon steel or stainless steel water going vessels; however, avoid zinc plated vessels
- **ISO Containers:** ISO containers are purpose built to allow solid and liquid products to be shipped seamlessly between varying modes of transportation. Ethanol compatible ISO containers are commercially available.

# SAFETY AND ENVIRONMENTAL

Identical to gasoline and other flammable materials, ethanol comes with some inherent risks in the event of a spill or fire. Ethanol, both in its liquid and vapor forms, is flammable. Even though ethanol burns clean, there will be a visible flame with very little smoke. As a regulatory requirement, ethanol used for fuel applications is typically "denatured" with a small fraction of petroleum product to make it unsuitable for drinking. This denaturant addition increases the amount of smoke produced during a fire. Ethanol is also water-soluble, which creates unique firefighting considerations when dealing with an ethanol fire or spill.

## Fires/Flammability

Chemical characteristics of a fuel will vary depending on the amount of ethanol blended into the fuel.

The fact that ethanol is both flammable and water soluble means if water is added to an ethanol-blended fuel, the ethanol will absorb the water and the gasoline component of the fuel will separate and rise to the top. Rather than water, the use of alcohol-resistant aqueous film-forming foam (AR-AFFF) is the recommended strategy for extinguishing an ethanol fire.

While traditional foams have long been used in extinguishing hydrocarbon fires and even gasoline containing up to 10% ethanol, the type of foam used for higher concentration ethanol fires must be alcohol resistant (AR-type). AR-type foam forms a tough membrane between the foam blanket and the alcohol fuel, preventing the alcohol from absorbing the foam. This type of foam also works well on gasoline fires, so it is the recommended choice for all fuel fires involving gasoline or ethanol-blended fuels.

### Characteristics of Gasoline and Ethanol Fuels

| Fuel | Flash Point | Auto-Ignition Temperature | Vapor Density (Air = 1) | Vapor Pressure | Boiling Point | Flammable Range (LEL-UEL) | Conductivity | Smoke Characteristics | Solubility In Water |
|---|---|---|---|---|---|---|---|---|---|
| Gasoline | -45°F | 530-853°F | 3-4 | 38-300mmHg | 100-400°F | 1.4%-7.6% | None | Black | None |
| E85 Blended Fuel | >-5°F | 495-689°F | 2.0-4.0 | 7-15 | 80-435°F | 1.4%-19% | Good | None-Slight | High |
| Denatured Fuel Ethanol | -5°F | 689°F | 1.5 | 4.5 | 165-175°F | 3%-19% | Good | None-Slight | High |
| E100 Neat Ethanol | 55°F | 793°F | 1.1 | 2.3 | 173°F | 6%-36% | Good | None-Slight | High |

Data Source: Ethanol Emergency Response Coalition

## Spills

Ethanol spills must be dealt with immediately to avoid unnecessary impacts to the environment. Yet, when compared to spills of other hazardous chemicals, like methyl tertiary-butyl ether (MTBE) and gasoline, ethanol tends to have fewer negative effects on the environment, and the effects are of a relatively short duration.

Ethanol is a naturally-occurring chemical in the environment, and it degrades rapidly in soil, groundwater and surface water. Predicted half-lives range from 0.1 to 10 days, depending on the environment in which the spill occurs. Ethanol completely dissolves in water, unlike MTBE, and once dissolved, vaporization and the formation of any sort of film are unlikely.

## Cleanup

Once again, the fact that ethanol is soluble in water creates specific considerations when cleaning up a spill. Ethanol is readily biodegradable. When water is an element of the spill environment, the ethanol and gasoline will separate. An ethanol/gasoline blended fuel can form layers in water, with gasoline floating on the surface of the water and ethanol mixing with the water below.

Surface-water spills can be remediated in a variety of ways depending on the type of surface water affected (streams, rivers, wetlands, saltwater, inner-harbor or open ocean, etc.). Methods include using earthen dams, booms (designed to absorb water-soluble materials), aeration, controlled burn or simply monitoring the situation and letting it dilute naturally to a non-toxic concentration.

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