Multiple engineering studies are calling for future fuel properties to meet the challenges of new vehicle technology and emissions regulations. As we identify the fuel properties that would provide solutions to these challenges, we must also keep the cost to consumers in mind. Successful solutions must have market potential, credible supporting data, and the support of regulators and industry. The purpose of this paper is to present a viable plan for providing a high performance, low-emissions fuel for tomorrow’s vehicles that also provides the health benefits of lower emissions for today’s vehicles.

What About Tomorrow’s Vehicles?

Tomorrow’s vehicles will have to meet historically high fuel efficiency and emissions standards. Meeting these standards will naturally bring about advancements in vehicle and engine design. It seems logical that development of future fuels needs to be done simultaneously with engine development. The auto industry needs to know what the octane and emissions profile of future consumer fuels will be so they can design engines that work with those fuels to meet the required mileage/carbon dioxide (CO2) per mile and emissions reductions. To design the high-performance engines that will work with future low-emissions consumer fuels, the auto industry needs a corresponding certification fuel today, when they are designing tomorrow’s engines. It would, obviously, be difficult to optimize an engine to run on a clean, high-octane consumer fuel if there wasn’t a corresponding certification fuel and vice versa.

What Do Tomorrow’s Fuels Need to Look Like?

Tomorrow’s fuels need to

► have consistent fuel properties that automakers can rely on to help their more-finely-tuned engines meet efficiency and emissions requirements.
► have high octane values for the higher compression ratios that new engines need to meet fuel efficiency (CO2 per mile) regulations.
► produce cleaner emissions to meet regulatory requirements and reduce health risks.
► be as inexpensive to the consumer as possible.

Where Do We Start?

We start with a good base fuel. With regulations getting tighter, the base fuel E10 needs to be consistent so the
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automakers and the fuel suppliers will know what they are starting with. The base fuel needs to meet a set of measurable criteria. The formulas, indices, and test methods used to measure those criteria need to be applicable to current technology and produce usable performance-related data. The base fuel needs to be optimized to burn as efficiently and cleanly as possible to increase efficiency and decrease emissions in as many of today’s and tomorrow’s vehicles as possible and to maximize the benefits of adding ethanol.

One of the reasons that setting measurable criteria for today’s base fuel is important is that most gasoline by itself, before the ethanol is added, doesn’t have enough octane to be sold to consumers, and the fuel properties of the gasoline by itself can vary substantially. Thus, while the E10 fuels that go to the consumer have the octane and other emission values of ethanol, their contribution to efficiency and emission levels may fluctuate. With tighter efficiency and emissions regulations and more finely-tuned engines, less variability in the base fuels would logically provide a more ideal response.

Can We Really Get High Octane AND Low Emissions?

There is no question that “efficiency enhancements (to engines) such as higher compression ratios and forced induction (turbocharging) profit from more octane.” (Road and Track) There is also more than one way to increase octane levels in gasoline; but many of the available octane boosters have a negative effect on emissions and emission-control equipment in vehicles. Ethanol, however, provides high octane levels while at the same time reducing overall emissions, especially some of the more toxic polycyclic aromatic hydrocarbons (PAHs).

An E30 blended fuel will give the auto industry a clean, high octane fuel to design to. An E30 blended fuel is backed by creditable data; mid-level ethanol blended fuels have already shown market potential; and there is growing consensus that this is a solution to efficiency and emissions regulations that could be supported by regulators, the auto industry, and the oil industry. The sections below demonstrate how a mid-level blended fuel like a E30 could be the most viable solution available to meeting the challenges of new vehicle technology and emissions regulations while also decreasing emissions in today’s vehicles.

Will There Be Enough Ethanol For An E30 Fuel?

Before we look at the details of this potential solution, it is prudent to address a question that many people might ask: Will there be enough ethanol for an E30 fuel. The simple answer is yes. Future fuel sales for light-duty vehicles are not anticipated to increase significantly; and as new, more efficient vehicles continue to enter the market there could even be a slight reduction in fuel sales for these vehicles. The Renewable Fuels Standard (RFS) and the natural course of supply and demand in the market indicate that there will be sufficient ethanol to meet the ethanol demands for an E30 blended fuel. In addition, the influx of new vehicles into consumer’s hands is relatively slow, especially when many consumers are keeping their cars longer, as they are now. Furthermore, just as today not all vehicles are designed for premium gasoline, not all vehicles would be designed for an E30 blended fuel. Many on-road vehicles, plus off-road vehicles and small engines, will still be designed to the E10 base fuel.

Engine Efficiency and Octane From Ethanol

The main challenge of new vehicle technology is improving engine efficiency. Octane is the fuel property that is essential for helping automakers increase engine efficiency. Ethanol has high octane levels and is widely used in fuels as an octane booster. Figure 1 shows the power output potential of engines using fuels with varying amounts of ethanol. The data is from tests that supported Society of Automotive Engineers (SAE) paper 2012-01-1277. It shows that efficiency is increased with increased ethanol. The primary reason for the increased efficiency is twofold. First, ethanol burns more efficiently than gasoline; and second, octane enables the engine to operate at higher loads which allows higher efficiency. Today, most non-turbocharged vehicles will not operate beyond a power output potential of 10, as
indicated in Figure 1. New high compression engines or engines equipped with turbocharging still don’t operate much into the gray area on the right.

It can also be seen in Figure 1 that higher ethanol blends can perform in diesel-efficiency territory. However, it is hard to imagine that future engines could be economically built to be flexible enough to take advantage of both high and low blends of ethanol. Therefore, this data shows that an E30 blended fuel provides the most opportunity for higher power output potential at a blend level that is practical.

**What About That Cooling Effect?**

A new awareness is rising among engineers about performance versus measured benefits of ethanol in mid-level blended fuels like E30. The SAE 2012-01-1274 paper has shown that the measured octane (research octane number or RON) from E0 to E30 is significantly higher than the measured octane performance from E30 to E85. However, the current octane measurements, do not show the benefits of ethanol’s cooling effect. In Figure 2, SAE 2012-01-1277 paper shows that an E30 fuel blended with today’s regular, consumer fuels (88 RON) has a 100 RON octane value, and demonstrates the increased octane value of cooling effect. This results in an increased RON value for E30 to near 108. With the cooling effect applied, there is nothing in a gallon of gasoline that offers the same octane potential as ethanol.

**What’s the Next Step Toward Improved Efficiency With Ethanol?**

Based on the data shown here and other supporting data, Urban Air Initiative, Inc. is promoting the following solutions.

1. Maintain E10 as the base fuel but make blending improvements that benefit the vehicles on the road today, as well as off-road vehicles and small engines.

2. For on-road vehicles, all fuel blends above E10 are created by simply adding ethanol.

As stated in the introduction, fuel improvements need to be made simultaneously with advances in new engine and vehicle technology.

The message about the importance of octane and the sources of octane also needs to be communicated so that it is understood better, especially since its importance will increase with new vehicles.
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Getting the Octane Message Out

Getting the octane message to consumers will take time and a concerted effort. It is also likely that more regulators and policy makers need to understand octane at a higher level. It may be true for older cars that higher octane values or using the designed-for octane isn’t critical, but for newer vehicles with higher compression ratios, the negative impact of using a fuel with an octane value lower than the vehicle is designed for is important. In new high efficiency vehicles, not using the fuel with the correct octane level will have a measurable negative impact on the performance of the vehicle.

In older vehicles and many vehicles on the market today the source of octane is significant; consumers may not benefit on a cost-per-mile basis for higher octane if they are purchasing premium gasoline from the petroleum companies (which often contains octane from sources with a high aromatic content). Some new studies are showing, however, that in today’s vehicles small additional amounts of ethanol may offer equal mileage with a lower cost per gallon. This means lower cost per mile for consumers. This also benefits the consumer by ensuring that the octane is from a known and low-emissions source.

Switching Gears: What About Emissions?

Today, regulated emissions like carbon monoxide (CO), volatile organic carbons (VOCs), and nitrous oxides (NOx) are tightly controlled with even stricter regulations anticipated in the near future. There is also growing concern about health risks from the aromatic hydrocarbons in emissions, especially polycyclic aromatic hydrocarbons (PAHs), some of which are not regulated. Urban Air Initiative was started to raise awareness about the health risks of PAHs. Multiple automotive studies are also raising similar concerns; and several are calling for cleaner fuels to be developed.

What is Particulate Matter?

Particulate matter is the particles that are emitted from a vehicle’s tailpipe. The particulate matter in the emissions from gasoline spark-ignited engines is too small to see since from the tailpipe they are smaller than the spectrum of light. Ultrafine particulates (UFPs), for example, have 100 times more surface area than particulate matter that is 2.5 microns in diameter. The smaller a particle is, the farther it can penetrate into the lungs. Multiple health studies are connecting serious health concerns from UFPs to human proximity to freeways. Another growing concern is that some of particulate matter is regulated and some isn’t.

What Are Aromatic Hydrocarbons?

Aromatic hydrocarbons are a form of benzene and significantly contribute to smog-forming emissions. Different aromatic hydrocarbons evaporate at different temperatures. Aromatic hydrocarbons (distill) at higher temperatures pose increased health concerns because they are the building blocks for higher levels of particulate matter and PAHs.

The temperature at which all of a fuel has evaporated (distilled) is called the final boiling point. T90 is the temperature at which 90% of the fuel has evaporated. The T90 and T95 of a fuel is a good indicator of the aromatic make-up of a fuel. To reduce the level of the more toxic aromatics in a fuel, regulators can set limits on the T95 distillation temperature and the final boiling point.

Does the Data Support the Concerns?

Several sources of data support the link between health concerns and emission levels, but two studies by Honda Motors have been key to Urban Air Initiative’s assessment of the health issues surrounding particulate emissions.
Honda Motors’ SAE papers 2010-01-2115 and 2010-01-2117 identified a means of calculating the propensity of fuel to form particulates. This study wasn’t focused on ethanol; it was primarily focused on fuel make-up and particulate matter formation. As Urban Air Initiative began to utilize this calculation, it became clear that many consumer fuels need to change. When consumer fuels average two to three times more particulate matter than certification fuels, some of these studies are even more concerning, especially in urban areas.

In 2012, Urban Air Initiative took three vehicles to a certified testing laboratory in Ann Arbor, Michigan. Figure 3 shows the particulate accumulation over a Federal Test Procedure (FTP) drive cycle (11-mile city drive cycle). The particulate accumulation of the E0 consumer fuel was more than double the particulate accumulation of the E0 certification fuel. (E0 means 0% ethanol, E30 means 30% ethanol, etc.) The decrease in particulate accumulation from the E0 consumer fuel to the E30 and E85 consumer fuels was due to simply adding ethanol to the E0 consumer fuel. Figure 3 clearly shows a very significant drop in particulate accumulation simply from adding ethanol. It is interesting to note that simply adding ethanol to the E0 consumer fuel created fuels with particulate accumulations less than the E0 certification fuel.

Data from 2009 and 2011 State of Texas gasoline surveys show that the average aromatic content in regular 87 octane gasoline is 25 percent. The average was the same for premium gasoline but with much more variation. This suggests that high aromatic content is one way to ensure minimum octane requirements.

Utilizing Honda’s predictive modeling index (PMI) in the 2011 State of Texas survey, Figure 4 shows the PMI contribution of the aromatics from 46 fuel samples. (The PMI predicts particulate number trends and total particulate mass regardless of engine type or test cycle.) The lower-distillation temperature aromatics [the BTEX (benzene, toluene, ethyl benzene, and xylenes) aromatics] are about 15% of the gasoline volume by weight with a 12% PMI contribution. Aromatics that distill (evaporate) at higher than 300°F are also about 15% of the gasoline volume by weight but with a 75% PMI contribution. The discrepancy is even larger for aromatics that distill at temperatures above 400°F. The results of this survey should be central in the discussion about cleaner fuels. Decreasing the final boiling point and T95 temperature limits must be included in the discussion about reducing the levels of these toxic emissions.
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How Do We Clean Up Those Most Toxic Emissions?

As previously described, the T90 to T95 distillation temperatures of a fuel are directly related to the aromatic make up of a fuel. Higher T90 distillation temperatures correlate to higher levels of the more toxic aromatics.

Figure 5 shows the T90 temperatures of 88 fuels from the State of Texas survey. The fuels were grouped by their average Reid vapor pressure (RVP): 7.4 psi, 9 psi, and 7 psi. RVP is a required measure of the volatility of gasoline. It is defined as the absolute vapor pressure exerted by a liquid at 100°F (37.8 °C) as determined by the test method ASTM-D-323. To reduce evaporation emissions due to seasonal temperature changes, refineries adjust the RVP seasonally to maintain gasoline standards.

In Figure 5, the regular 87-octane fuels from the Dallas and Houston area (7 psi RVP) had a lower average T90 distillation temperature than the fuels with an RVP of 7.4 psi. However, the PMI average was no better than the 9.0 RVP fuels. Today, the average PMI seen in certification fuels test is 1.4–1.5 on average. From the noted increases in testing, particulate emissions in the State of Texas are two to three times higher than currently-used certification fuels.

Where Does Ethanol Fit Into Cleaner Emissions?

Ethanol provides cleaner emissions in multiple ways.
► Ethanol by itself does not contribute to the formation of particulate matter.
► Diluting fuel by simply adding ethanol has created significant reductions in PAH and particulate matter emissions.
► The percentage reduction in emissions from simply adding ethanol can be greater than percentage of ethanol added to a fuel. (For example, in SAE paper 2010-01-2129, adding 20% ethanol resulted in a 30–40% reduction of emissions.)

Other Issues: Reid Vapor Pressure

Current regulations focus on reducing RVP to reduce evaporative emissions; but reducing RVP with aromatics has a negative effect on particulate matter emissions. Vehicle technology has been the focus of improving cold starts and reducing particulate matter emissions, but fuel is also an important factor. In blending with ethanol, the vapor pressure generally peaks at E8 to E10 but with additional ethanol added the vapor pressure decreases.

Other Issues: Is The Drivability Index Up-to-Date?

Currently, the ASTM standard D4814 Drivability Index (DI) includes an adjustment for adding ethanol. (The DI is used to ensure the cold-start and warm-up performance of a vehicle. See Figure 6 for the DI equation.) However, because ethanol evaporates at or near T50 and the adjustment for ethanol is made at the end of the DI rather than to the T50 temperature, higher distillation aromatics can be added to a fuel and still be within the regulated limits. To really make the most improvement to vehicle emissions from fuel, the DI should be adjusted to accurately account for the particulate emissions.
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Figure 6

Driveability Index: 1.5*T10 + 3*T50 + T90 + 2.4*Vol% Ethanol

What’s the Next Step Toward Reduced Emissions With Ethanol?

As proposed for increasing octane levels for improved engine efficiency, maintaining an improved E10 as the base fuel and simply adding ethanol for higher-octane fuels will, by itself, reduce the aromatic content and particulate matter emissions because of the inherent lack of aromatics in ethanol.

In addition, based on the data shown here and other supporting data, Urban Air Initiative is proposing the following distillation temperature limits for fuel for gasoline engines.

- A 360°F T95 distillation temperature limit
- A 380°F final boiling point

Conclusion

The improvements that a mid-level ethanol blend like E30 makes to the octane and emissions profiles should be of great interest to everyone who is working hard to meet the new efficiency and emissions standards.

An E10/E30 solution also offers a valuable market approach for current and future off-road vehicles, small engines, and vintage vehicles.

An E10/E30 solution is a viable plan backed by credible supporting data; it has already shown market potential; and it is a balanced plan that consumers, the auto industry, the oil industry, and regulators could support.

The low cost of ethanol already gives consumers a break at the pump. Utilizing ethanol to help improve engine efficiency and vehicle emission levels could also give consumers a break at the car lot.

Figure 7

Ethanol’s Clean High Octane Advantage

“Nothing in the Gasoline Distillation Range can Match Ethanol’s Octane”
Reference CRC Project No. CM-137-1b (cites SAE paper 2012-01-1277)

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<th>CO2 Reduction at the Wheel</th>
<th>Emissions Benefit</th>
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<tr>
<td>E30 (ethanol +E10) +10 Octane</td>
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Figure 7 summarizes the goals of reaching higher octane levels for improved mileage benefit, and compares the differences between current consumer premium fuel and consumer regular fuel with ethanol added.
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E30\textsubscript{98 RON}

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