Engine Manufacturers Association®

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Technical Statement on the Use of Oxygenated Gasoline Blends in Spark Ignition Engines

INTRODUCTION

The Engine Manufacturers Association ("EMA") is an international membership organization representing the interests of manufacturers of internal combustion engines.

Increased worldwide interest in reducing reliance on petroleum-based fuels and improving air quality has prompted broadened use of alternative, renewable fuels, including gasoline blended with various oxygenates. Regulatory agencies around the world have adopted plans requiring the use of renewable fuels, and international standard-setting bodies have approved specifications regarding their use. Understanding the importance of developing new technologies without compromising emission or performance benefits, EMA and its members have actively participated in many of these public and private initiatives.

This Technical Statement sets forth EMA's position on the use of gasoline blended with ethanol[1] (gasoline ethanol blends) in current engine technologies. While this Technical Statement primarily focuses on issues relevant to small nonroad spark ignition engines, a significant amount of the information included is applicable to other categories of engines or vehicles intended to operate on conventional gasoline. However, it should be noted that EMA's current position is limited by the general lack of available research on the use of gasoline ethanol blends containing greater than 10 volume percent ethanol (E10) in products designed to comply with stringent emission regulations (not including flexible fuel vehicles intended to operate on blends containing up to 85 volume percent ethanol (E85)).

EMA recognizes that interest in reducing greenhouse gas emissions, such as CO_2, has resulted in increased analysis of the life cycle emission characteristics of fuel blending components such as ethanol. However, this Technical Statement does not address the direct or indirect effect of ethanol production or use on greenhouse gas emissions.

ETHANOL FEEDSTOCK

Ethanol has been used for many years as a blending component for gasoline at a maximum of 10 volume percent. Such use has historically been on a seasonal basis, and has been centered primarily in regions required to meet U.S. EPA reformulated gasoline requirements. Ethanol can be derived from a broad variety of renewable sources such as corn, cellulose and sugar cane. The source, or feedstock, used to produce ethanol varies by region. For example, corn based ethanol is common in the United States, while sugar cane based ethanol is common in Brazil. In addition, in an on-going effort to improve the economics and greenhouse gas emission benefits of the use of ethanol as a gasoline blending component, alternate feedstocks, such as cellulose, continue to be investigated. Regardless of the feedstock, finished ethanol is a single molecule product with consistent chemistry.

[1] This Technical Statement does not address other oxygenate blending components such as ethers.

ETHANOL and BLEND SPECIFICATIONS

Several international organizations have adopted and continue to revise ethanol specifications and guidelines. One such specification is ASTM International D4806: Standard Specification for Fuel Ethanol for Automotive Spark-Ignition Engines. Current ASTM specifications are limited to blends below E10 (ASTM D4814), and blends between E70 and E85 (ASTM D5798). In March 2009, the Worldwide Fuel Charter Committee (WWFC), of which EMA is a member, published Ethanol Guidelines for E100 ethanol used in E10.[2] Adherence to such specifications and guidelines is crucial to the effective use of gasoline ethanol blends in engines.

ETHANOL - GASOLINE BLENDS

Ethanol has a single molecular compound and therefore a single temperature at which liquid fuel vaporizes. Petroleum based gasoline is a blend of a number of different hydrocarbons that vaporize at significantly different temperatures (this is often referred to as a “distillation curve”). The vapor pressure created at a defined temperature and the percentages of the fuel vaporized at any given temperature are critical parameters that determine the performance of the engine. Initial vapor pressure is critical for cold engine starting. Mid-range or T50 distillation characteristics significantly influence engine warm-up and acceleration, and high-end or T90 distillation characteristics have a significant influence on crankcase dilution. As ethanol content is increased when blended with traditional gasoline, the initial vapor pressure is increased. However, the mid-range distillation characteristics are lowered. To counter these tendencies a special type of petroleum gasoline, known as blendstock, is used in the blending process. Depending on the desired ethanol content, the appropriate blendstock is used in order to assure that the finished fuel blend has similar characteristics as conventional gasoline.

In the United States, both lawmakers and government agencies have pursued efforts to promote and regulate the use of oxygenated gasoline blends for many years. Through the creation of the original renewable fuel standard in 2005 (“RFS”) and subsequent legislative action (namely, the U.S. Energy Independence and Security Act of 2007 “EISA-2007”), U.S. EPA and Congress created a framework for the replacement of conventional petroleum fuels with renewable fuels. The recent RFS-2 proposal continues EPA’s efforts to incorporate the increased renewable fuel production requirements specified by EISA-2007 and increases annual production requirements for alternative fuels, including ethanol, beginning in 2009. Based on the EISA-2007 requirements, the RFS-2 proposal would require the production of 11.1 billion gallons of alternative fuel in 2009. Under the RFS-2 proposal, production requirements would continue to increase each year, reaching 36.0 billion gallons of alternative fuels to be produced in 2022. Further, several other regional and national standards requiring increased use of renewable fuels, including ethanol, either are in place or under review.

Based on their current understanding of ethanol gasoline fuel blends, EMA members expect that blends up to a maximum of E10 should not cause engine or fuel system problems, provided the blend is not exposed to excess free water.

Engines and vehicles specifically designed for use of higher ethanol-gasoline blends, typically referred to a flex-fuel vehicles, include features that allow the use of up to 85% ethanol gasoline blends (E85) through the use of special materials and feedback control mechanisms that

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[2] Available on EMA’s website: [E100 Guideline Final]

adjust the fuel delivery and engine combustion control parameters based on the combustion process in real time.

In early March 2009 Growth Energy filed a Clean Air Act Waiver Application to Increase the Allowable Ethanol Content of Gasoline to 15 percent (Docket ID No. EPA-HQ-OAR-2009-0211) ("Growth Energy Waiver") with U.S. EPA. In its waiver application, Growth Energy requested that ethanol blends up to 15% by volume (E15) be considered substantially similar to traditional gasoline. EPA published a request for comments regarding the Growth Energy Waiver in late April 2009.[3] EPA issued a letter to General Growth on November 30, 2009 indicating that (i) the testing required to approve their waiver request was not complete; (ii) testing of light-duty vehicles is expected to be complete by August 2010; and (iii) if the additional test data continues to be supportive a waiver for use of E15 in 2001 model year and later light-duty vehicles could be approved. Based on the potential for a bifurcated approval, EPA is evaluating pump labeling and other methods to prevent misfueling of earlier model year light-duty vehicles and nonroad engines/equipment.

The required EISA-2007 and proposed RFS-2 renewable fuel production requirements have resulted in significant speculation that renewable fuel content in conventional gasoline blends will be required to exceed E10. As a result, significant industry and government testing programs are in process to evaluate E15 and E20 blends in non-flex-fuel vehicles and other products that use conventional gasoline (such as small and large nonroad spark ignition engines, marine engines, motorcycle and recreational vehicle engines).

ENGINE OPERATION, PERFORMANCE AND DURABILITY

The energy content of neat ethanol (E100) is about thirty-five percent (35%) lower than that of petroleum-based gasoline (on a volume basis). Actual power loss and fuel economy reduction associated with ethanol blends will vary depending on the percentage of ethanol blended in the fuel and the engine's ability to adjust combustion control parameters. Adjustments to the engine in service made to compensate for such power loss or fuel economy reduction is a real concern and may result in a violation of EPA's anti-tampering provisions. To avoid such illegal tampering, as well as potential engine problems that may occur if the engine is later operated with petroleum-based gasoline, EMA recommends that users not make such adjustments.

Higher percentage ethanol blends (greater than E10) can cause a variety of engine performance problems as a result of (i) the enleanment effect associated with the oxygen content of such blends on a volume basis; (ii) changes in ignition and combustion parameters; and (iii) the differences in fuel properties. The differences in fuel properties increases the corrosion of metals and swelling of elastomers, both of which increase further with increasing ethanol content. These problems are avoided in flex-fuel vehicles through the use of (i) feedback control systems that adjust fuel delivery and ignition timing; and (ii) materials that are compatible with high ethanol content fuels. Products that are either designed to operate on higher ethanol blends or not required to meet stringent exhaust emission requirements (such as products designed to operate using E25 in Brazil) are able to avoid such problems.

Many nonroad engines, particularly smaller air cooled engines, utilize a richer than stoichiometric air-fuel ratio in order to enhance engine cooling over the wide range of typical

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[3] FR Vol. 74, No. 75/ Tuesday, April 21, 2009, reference Docket ID No.: EPA-HQ-OAR-2009-0211

operating conditions. This is particularly the case under high load conditions. Additionally, these small engines typically use very simple carburetors for air-fuel ratio control with limited capability to provide enrichment during acceleration or warm up operation. A very limited number of small nonroad engines use fuel and spark control systems that are reactive to engine combustion, however, even the most sophisticated of such systems are not comparable to the complex systems integrated into flex-fuel vehicles. In addition, such fuel and spark control systems have significant limitations and their use results in a substantial increase in the incremental cost of such engines over traditional engines. As a result, fuel and spark control systems are generally only utilized for specialty applications or high performance products where the benefits outweigh the significant costs.

The enleanment effect of increasing ethanol content is significant for engines that utilize fixed calibration fuel delivery systems (e.g. conventional carburetors) and fixed ignition timing. Engine manufacturers have worked diligently to find an acceptable combination of fuel and ignition system calibration that can tolerate a range of fuel from neat petroleum gasoline up to E10 that both complies with all U.S. EPA regulatory requirements and provides acceptable operation for the end user. Increasing ethanol content causes further enleanment which results in higher combustion temperatures thereby increasing exhaust gas and engine component temperatures. This enleanment influence on engine component temperatures can damage the engine. For example, it can cause exhaust valve sealing degradation, piston scoring, and/or cylinder head gasket failure. The potential for engine damage is greater for engines with fuel systems already at the lean end of production tolerances and/or twin cylinder engines that often have air-fuel ratio differences between cylinders due to system dynamics over the engine operating speed and load range. In addition, further enleanment renders the combustion process less consistent from combustion cycle to combustion cycle. This inconsistency is particularly evident in one and two cylinder engines that utilize load sensitive governing systems to maintain engine speed because the governor system response can amplify engine speed fluxuations into audible surging (often referred to as hunting). While limited information is available, engine manufacturers anticipate that it would be possible to effectively calibrate engines to operate on a higher ethanol content blend (such as E20) provided that these engines were not operated outside of the target ±5% ethanol content blend range. Accordingly, it is imperative that a single blend value is selected and that operation and compliance with regulatory requirements be limited to the designated blend level. However, selection of a single blend value for future product does not address the large population of legacy engines that require E10 or lower blends.

Engines are designed to prevent pre-ignition, or knock, because the extreme pressures created by pre-ignition can result in severe damage to engine components. Conventional gasoline is identified by its anti-knock characteristics (known as octane). In the U.S., pump grade gasoline is generally available in three octane ranges: regular, mid-grade and premium. Ethanol has a very high octane rating compared to conventional gasoline and therefore can provide a significant increase in octane depending on the blend level. The highly sophisticated engine control systems found in flex-fuel vehicles adjust combustion parameters to achieve the desired engine performance by taking advantage of the higher octane characteristic of ethanol. Conventional engines, particularly small nonroad engines utilizing fixed fuel and ignition timing, are not able to take advantage of the higher octane provided by higher ethanol blends unless they are designed to exclusively operate on the higher blend. Engines designed to operate on higher octane fuel will experience pre-ignition when operating on lower octane conventional gasoline, resulting in significant damage to engine components. Gasoline blenders utilize the higher octane provided to ethanol to allow the use of lower octane, generally less expensive, hydrocarbons in blend stocks such that the finished fuel blend has similar anti-knock characteristics as conventional gasoline.

EMISSION CHARACTERISTICS

Multiple agencies have published reports on the emission effects of ethanol-gasoline blends. The majority of these reports apply only to light-duty vehicles that have some form of combustion feedback control for both fuel delivery and ignition timing. The most comprehensive report covering nonroad engines and equipment was conducted by the Orbital Engine Company[4]. In addition, a recent report published the results of testing conducted for the U.S. Department of Energy (DOE)[5] which included testing for selected nonroad engines ("DOE Report"). However, EMA members have significant concerns with the DOE Report's data analysis and conclusions. Such concerns are specifically outlined in EMA's comments to the Growth Energy Waiver filed with EPA on July 20, 2009.

Ethanol blends traditionally were used in place of petroleum-based gasoline to reduce hydrocarbon emissions in various regions during certain seasons. The enleanment affect of the ethanol reduced overall hydrocarbon and carbon monoxide emissions while increasing NOx emissions from engines without feedback controls, and provided higher exhaust gas temperatures that enhanced oxidation type aftertreatment system performance, particularly on cold engine starting. The value of these ethanol blends diminished as light-duty engine designs incorporated more advanced closed loop control systems and aftertreatment systems were modified to improve cold start emissions.

Evaporative emissions also are regulated in the U.S. for many, if not most, engine powered products. Ethanol is known to have higher permeation emissions as well as an influence on diurnal emissions. Small nonroad engine emissions are regulated by both U.S. EPA and the California Air Resources Board. In compliance with U.S. EPA regulations, manufacturers of small nonroad engines are in the process of implementing evaporative controls into small nonroad engines. Both regulatory agencies have identified significant permeation emissions through non-metallic fuel lines and fuel tanks. Recognizing the influence of ethanol on these permeation emissions, the U.S. EPA requires that nonroad evaporative emission testing is conducted using E10 fuel. Additional increases in evaporative emissions from either uncontrolled non-metallic fuel lines or fuel tanks due to increased ethanol content are not known at this time. However, preliminary information indicates that some increase can be anticipated.

STORAGE AND HANDLING

Poor blending practices can result in significant discrepancies between the intended blend and the uniformity of the actual blend delivered. Accordingly, it is important to take all necessary steps to ensure the uniform blending of ethanol blend stock and petroleum gasoline. Splash blending should only be conducted with careful monitoring of the consistency of the

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[4] Market Barriers to the Uptake of Biofuels Study – A Testing Based Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel blend on Non-Automotive Engines (May 2003)

[5] Effects of Intermediate Ethanol Blends on Legacy Vehicle and Small Non-Road Engines, Report 1, prepared by Oak Ridge National Laboratory for the U.S. Department of Energy (October 2008, updated February 2009)

blend. Injection blending systems typically provide acceptable uniformity but should be verified on initial installation and periodically confirmed.

Ethanol and ethanol blends act as an adsorbent – removing free water from fuel storage or vehicle/equipment fuel tanks until the ethanol becomes saturated. If saturated, the ethanol water combination will undergo phase separation from the petroleum gasoline in the blend. If phase separation occurs significant problems can result, particularly if the fuel delivered to the engine is actually an ethanol-water mixture. Therefore, care must be taken to remove excess water from fuel tanks and appropriate measures must be taken to prevent water from entering fuel storage tanks or distribution systems. Nonroad engines are frequently fueled using portable fuel containers and stored in areas exposed to ambient conditions including high humidity and precipitation. As a result these engines often have significantly more water in their fuel systems than vehicles that receive fuel from the same retail fuel outlet, exacerbating the potential for phase separation.

Ethanol and ethanol blends also act as a solvent removing deposits that have formed in fuel storage tanks and distribution systems over years of service. The solvent effect increases with increasing blend levels.

In the U.S., the Underwriters Laboratory (UL) approves fuel handling and dispensing equipment such as the gasoline pumps used at service stations. UL has verified that ethanol blends of E10 and lower are acceptable for use in traditional service station pumps. UL is in the process of evaluating the suitability of E15 and E20 blends for use in traditional service station pumps. In addition, UL is in the process of identifying service station pump requirements for ethanol blends up to E85 that are utilized in flex-fuel vehicles.

Pumps dispensing multiple blend levels may result in significant blend level disparity when switching from high blend levels (e.g. E85) to neat gasoline or blends less than E10. This problem is exacerbated when filling small portable containers used to fuel nonroad engines or equipment. For example, if a one gallon container is being filled and there is 0.2 gallons of residual E85 in the pump from the previous purchase, the customer actually will inadvertently receive a 25% ethanol blend (E25) instead of the desired 10% blend (E10). Accordingly, it is critical that any pump system utilized to dispense different blend levels has an effective means of preventing the dispensing of higher than expected ethanol blend levels. In fact, it is likely that the only way to prevent unintentional blending will be to require a separate dispensing system for each blend.

HEALTH & SAFETY

Ethanol blended with gasoline generally results in lower hydrocarbon and carbon monoxide emissions from engines operating richer than stoichiometry, however, these same engines typically have increased NOx emissions and increased emissions of several other compounds such as aldehydes. The influence of such emissions is altered, sometimes significantly, by the use of closed loop fuel controls and three-way catalytic converters typical of current light-duty vehicles.

While ethanol blends alter the vapor and distillation characteristics of traditional petroleum gasoline, such changes do not significantly alter the inherent safety requirements associated with the storage and/or handling of the fuels.

WARRANTIES

Engine manufacturers are legally required to provide consumers with an emissions warranty on their products (which are certified to EPA's gasoline fuel specifications). Engine manufacturers also typically provide a commercial warranty. Individual engine manufacturers determine what implications, if any, the use of ethanol blends has on the manufacturers' commercial warranties. It is unclear what implications the use of unapproved ethanol blends has on emissions warranty, in-use liability, anti-tampering provisions, and the like.

ECONOMICS

The cost of ethanol blend stock varies depending on the basestock, production process, geographic area, variability in crop production, government tax incentives, and other factors. Although the cost of ethanol blend stock may be reduced if relatively inexpensive feedstock, such as cellulosic material, is used instead of corn or sugar cane, the average cost of ethanol blend stock nevertheless exceeds that of petroleum-based gasoline. In addition, ethanol price volatility mirrors gasoline price volatility in the commodities markets.

CONCLUSIONS

In summary, EMA has drawn the following conclusions with respect to the use of gasoline ethanol blends in current engine technologies:

- Regardless of the biomass feedstock or the process used to produce the fuel, E100 blend stock should be required to meet the requirements of ASTM D4806.
- Ethanol blends up to a maximum of E10 should not cause engine or fuel system problems, provided the E100 used in the blend meets the requirements of ASTM D4806 and the finished fuel meets ASTM D4814.
- Ethanol blends ranging from E70 up to E85 should be required to meet the requirements of ASTM D5798 and only be utilized in vehicles (or engines) identified as flex-fuel vehicles (or engines).
- Oxygenated gasoline blends should meet the fuel requirements specified by the engine/vehicle manufacturer for the product they are used in.
- Dispensing pumps should be required to use separate pump systems for blends up to a maximum of E10 and blends ranging from E10 up to E85.
- Although the actual power loss will vary depending on the percentage of ethanol blended in the fuel, E100 fuel's energy content is approximately 35% lower than that of petroleum gasoline. Ethanol blends of E10 and lower typically do not result in observable power loss or reduction in fuel economy.
- Ethanol blends reduce HC and CO exhaust emissions. Depending on the engine type and duty cycle, ethanol blends may produce increased NOx emissions compared with the emissions of petroleum-gasoline used in an unmodified engine. Engines designed to meet stringent emission regulations have not demonstrated additional reductions in HC and CO emissions or increases in NOx emissions when using ethanol blends. However, more testing is required to confirm the interaction between emission reduction strategies and ethanol blends.

- Evaporative emissions tend to increase with increasing ethanol content.
- Individual engine manufacturers determine what implications, if any, the use of ethanol blends have on the manufacturer's commercial warranties.
- Although several factors affect the ultimate cost of ethanol blend stock, its average cost exceeds that of petroleum-based gasoline.

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