Attachment: Proposed Rulemaking for Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards

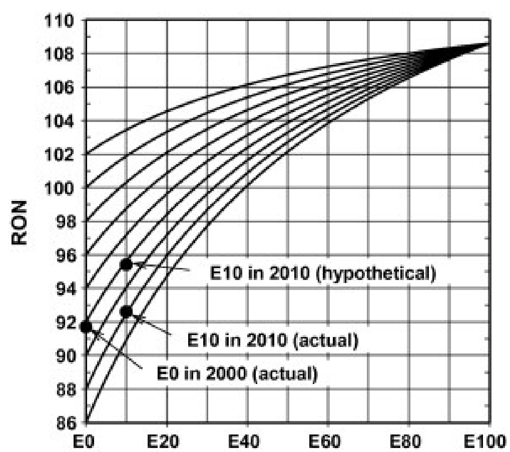
Docket ID No. EPA–HQ–OAR–2011– 0135

Supplemental Comments of Ford Motor Company

Appendix A: Literature Review of Benefits of High Octane/High Ethanol Fuels

In SAE paper 2009-01-2770[1], the implications of the RFS2 on the LDV fleet were explored and it was noted that "future vehicles will need to be built for compatibility with ethanol blends greater than E10, but that there has been little discussion beyond those blends expected a few years in the future." When developing the roadmap to ethanol blends higher than E10, OEMs must remain a key stakeholder in developing any regulations, as vehicles are designed several years before being built and remain on the road for an average of 15 years. Thus, a carefully orchestrated coordination between market fuel availability (which of course meets appropriate ASTM standards and OEM requirements) and vehicle compatibility must be considered during any rulemaking process. The SAE paper continues by citing that "FFVs provide maximum flexibility with respect to future ethanol content in gasoline. Widespread use of E85 and mid-level ethanol blends may also enable the introduction of dedicated vehicles that could realize greater fuel economy… Commitment and co-ordination from government, industry and consumers are needed to ensure long-term viability and sustainability of the modern biofuel industry."

In a 2012 article in the journal *Fuel*[2], the potential benefits of high octane number ethanol-gasoline blends were quantified. Historically, as the U.S. gasoline market transitioned from predominately E0 to predominately E10 today, the RON blendstock for blending with ethanol has been reduced to avoid octane "give-away." This has resulted in a lost opportunity to capitalize on the higher octane rating benefits which could be realized through blending ethanol as seen in Figure 1.



[1] Anderson, J., Hardigan, P., Ginder, J., Wallington, T., Baker, R.," Implications of the Energy Independence and Security Act of 2007 for the US Light-Duty Vehicle Fleet," SAE Powertrains, Fuels and Lubricants Meeting; 2009-01-2770.
[2] J.E. Anderson, D.M. DiCicco, J.M. Ginder, U. Kramer, T.G. Leone, H.E. Raney-Pablo, T.J. Wallington, High octane number ethanol–gasoline blends: Quantifying the potential benefits in the United States, Fuel, Volume 97, July 2012, Pages 585-594, ISSN 0016-2361, 10.1016/j.fuel.2012.03.017.

Figure 1[3]: "Estimated RON values for ethanol–gasoline blends with contour lines of constant blendstock RON. Also shown are data points for prevailing regular-grade gasoline in calendar years 2000 and 2010, as well as a hypothetical case for E10 if the RON of E0 found in 2000 had been maintained as the blendstock to create the final E10 blend in 2010."

Additionally, the importance of FFVs is outlined in the article, which notes that "FFVs could play an important transition role by providing compatibility with both E85 and future intermediate ethanol-content blends and could become desirable if higher ethanol blends are attractively priced. While FFVs could be optimized for high ethanol content fuels today, these vehicles would still need to provide competitive performance on the predominant fuel (E10) in order for them to be attractive to consumers at the time of purchase. An E85-optimized FFV that is fueled with a lower RON E0 or E10 fuel would show a considerable and unacceptable decrease in power and torque and a moderate increase in fuel consumption." Similar principles should be applied to the fueling infrastructure, which may require higher ethanol-blend compatibility upgrades. "The availability of a lower ethanol content (and thus higher energy content) fuel in the marketplace could be an obstacle to consumption of the higher ethanol content fuel….the higher ethanol content fuel would need to be attractively priced."

Finally, the article provided some significant conclusions, of note are the following;

1. Octane rating is a critical fuel property that plays a primary role in the design, operation, efficiency, and emissions of spark-ignited engines. Although the US federal government regulates LDVs in terms of fuel economy and emissions, the octane rating of the fuel necessary to achieve these objectives is not regulated. The octane ratings of gasoline have not increased since the early 1970s.

2. Higher minimum octane ratings for regular-grade fuel would enable higher compression ratios in future vehicles and is an opportunity to provide greater engine efficiency and meet increasingly stringent fuel economy regulations and expectations. Additionally, the change could benefit all vehicles powered by spark-ignited engines, including PFI and DI engines, hybrid electric vehicles (HEVs), and plug-in hybrid vehicles (PHEVs).

3. Fuel with higher octane ratings will also be increasingly important for advanced engines now being introduced that provide greater efficiency through downsizing and/or turbocharging, and that operate more often at high load where the most efficient operating conditions are limited by knock.

4. Substantial societal benefits could be obtained by capitalizing on the high octane rating of ethanol through the introduction of higher octane number ethanol–gasoline blends to the US marketplace.

In response to the opportunities identified and potential benefits that were postulated for higher ethanol/higher octane blends, engine and vehicle testing was done over the course of several studies.

[3] J.E. Anderson, D.M. DiCicco, J.M. Ginder, U. Kramer, T.G. Leone, H.E. Raney-Pablo, T.J. Wallington, High octane number ethanol–gasoline blends: Quantifying the potential benefits in the United States, Fuel, Volume 97, July 2012, Pages 585-594, ISSN 0016-2361, 10.1016/j.fuel.2012.03.017.

In SAE paper 2013-01-1321[4], the effects of octane and ethanol on engine and vehicle fuel economy and emissions were studied. The study included a Ford 3.5L EcoBoost GTDI engine and compared the effects of E10, E20 and E30 on fuel economy and CO_2 emissions. The engine design included stock compression ratio (10:1) and a higher compression ratio (11.9:1). At a CR if 11.9:1, the E20 splash blended fuel gave similar knock performance to the CR 10:1 engine with the E10 fuel. The E30 splash blended fuel at the higher compression ratio resulted in knock-limited performance that was equivalent to E20 at the stock compression ratio, which indicated that the E30 blend could have been operated in an engine with an even higher CR and still achieve acceptable knock behavior. At the higher CR, the E20 fuel resulted in a 4.8% improvement in the US EPA M/H CO_2 emissions with comparable full-load performance. The increased efficiency of the E20 fuel with the higher CR offset the decreased energy content, inherently associated with ethanol, of the E20 fuel such that the volumetric fuel economy (MPG) and driving range were similar to the baseline E10 at 10:1 CR. The E30 fuel at the higher CR gave a 7.5% benefit in CO_2 emissions for the US06 cycle while US06 highway MPG and range remained essentially unchanged. Figure 2 provides a clear visual representation that the higher CR enabled an increased volumetric fuel economy for the higher ethanol/octane rated fuels relative to the E10 91 RON fuel.

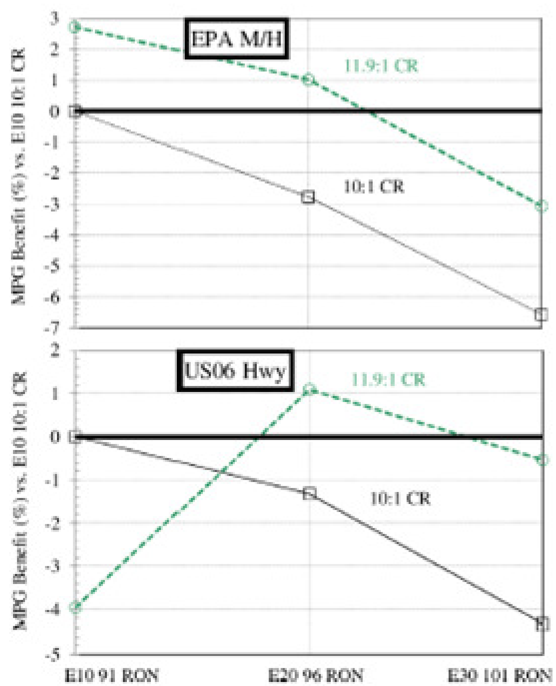


Figure 2: Volumetric Fuel Economy (MPG) Changes Relative to E10 at 10:1 CR

In SAE paper 2012-01-1277[5], the knock resistance of a matrix of different ethanol-gasoline blends was determined for a single cylinder engine with three types of fuel systems: upstream, pre-vaporized fuel injection (UFI); port fuel injection (PFI); and direct fuel injection (DI). The study drew the following conclusions:

[4] Jung, H., Leone, T., Shelby, M., Anderson, J. et al., "Fuel Economy and CO2 Emissions of Ethanol-Gasoline Blends in a Turbocharged DI Engine," SAE Int. J. Engines 6(1):2013, doi:10.4271/2013-01-1321.

[5] Stein, R., Polovina, D., Roth, K., Foster, M. et al., "Effect of Heat of Vaporization, Chemical Octane, and Sensitivity on Knock Limit for Ethanol - Gasoline Blends," SAE Int. J. Fuels Lubr. 5(2):2012, doi:10.4271/2012-01-1277

1. For a given gasoline blendstock, increasing ethanol content (using splash-blending) significantly increases both the knock- limited performance (NMEP) and thermal efficiency (NTE), especially at the retarded combustion phasing which is typical of modern turbocharged direct injection engines operating at high load.

2. Both the effect of chemical octane and the effect of charge cooling due to fuel vaporization on knock are very significant for high ethanol blends with direct injection, and are about the same order of importance.

3. At constant RON, increasing ethanol content significantly improves knock-limited NMEP at retarded combustion phasing, for fuels of ~99 RON and ~97 RON. This trend is not apparent for fuels of ~93 RON with ethanol content of 0 to 20% (by volume), due to the lower sensitivity of these fuels. This highlights the importance of increasing octane rating with increased ethanol content, rather than "match blending" future ethanol fuels to today's octane level. (Figure 3)

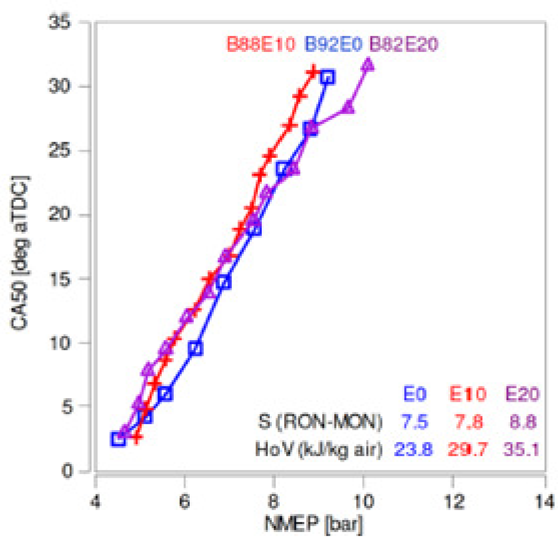


Figure 3: CA50 vs. NMEP for fuels of ~93 RON at 10:1 CR and 1500 rpm with DI

In SAE paper 2013-01-1634[6], the efficiency improvement for ethanol was determined using engine dynamometer testing and modeling analysis. A 5.0L V8 GTDI engine was operated at part load conditions with E85 and E0 gasoline (run in an alternating back-to-back pattern) where the engine was not knock-limited by either fuel. The results of the study showed "at equivalent part load conditions, E85 exhibits fundamental benefits in thermal efficiency and CO_2 emissions compared to E0 gasoline of about 4% and 7% respectively. Figure 4 shows the tailpipe equivalent brake specific CO_2 for the engine data sets from the study. For other ethanol-gasoline blends, it is expected that those benefits will scale approximately linearly with the fraction of

[6] Jung, H., Shelby, M., Newman, C. and Stein, R., "Effect of Ethanol on Part Load Thermal Efficiency and CO2 Emissions of SI Engines," SAE Int. J. Engines 6(1):2013, doi:10.4271/2013-01-1634.
It shall be noted that for both SAE papers 2013-01-1321 and 2013-01-1634, the CO2 benefits were computed as tank-to-wheels benefits, and do not account for the additional CO2 benefits of ethanol as a renewable fuel.

ethanol in the blend. These benefits are in addition to opportunities for improved efficiency which are available due to the greatly improved knock resistance of ethanol-gasoline blends."

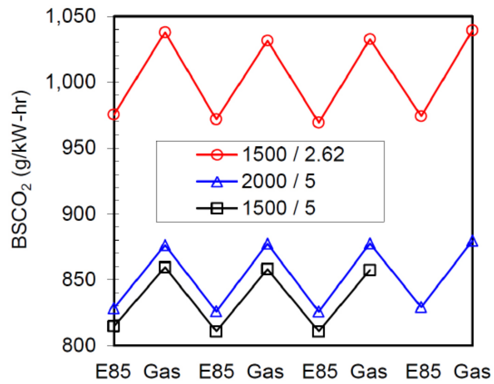


Figure 4: Tailpipe Equivalent Brake Specific CO_2 ($BSCO_2$)

Ultimately, a refinery study is needed to address the concerns for the net GHG accounting resulting from an increased octane rated new ethanol blended gasoline. To do so, the effect of increased octane rating and increased splash-blended ethanol linked to increased engine efficiency (reduced GHGs) needs to be compared to the changes in GHGs from the refinery to accommodate this new fuel. It is expected that an intensive study will be released and documented in the literature after the July 1st, 2013 Tier 3 comment due date. Included in the to-be released study are the costs and benefits associated with blending higher octane rated/higher ethanol blends. The study used a regional refinery linear programming (LP) model to estimate the effects on the U.S. refining sector. It is our understanding that the literature article will contain supporting information on this topic and there are plans to submit the report and article reference to the agency upon release.