Tank to Wheel Emissions of Ethanol and Biodiesel Powered Vehicles as Compared to Petroleum Alternatives

White Paper

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July 2010

Published by:

Center for Transportation Studies
University of Minnesota
200 Transportation and Safety Building
511 Washington Ave., SE
Minneapolis, Minnesota 55455

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Tank to Wheel Emissions of Ethanol and Biodiesel Powered Vehicles as Compared to Petroleum Alternatives

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January 16, 2010

Executive Summary

Air quality modeling of the air pollution effects of alternative fuels must be supported with data on the tailpipe emissions of those fuels relative to conventional fuels. Here a literature review is presented of the tailpipe and evaporative emissions from 85% ethanol (E85), 10% ethanol (E10), and 20% biodiesel (BD20) compared to conventional fuels. It is found that E85 causes both positive and negative changes in emissions relative to gasoline, depending on the pollutant, and the changes in some pollutants have an uncertain sign. E10 and BD20 in general exhibit smaller changes in emissions compared to E85, the impacts of which cannot be fully known without air quality modeling.

1 Introduction

Biofuels have been the subject of much debate in regard to their viability as a replacement for petroleum fuels. However, much of this debate has centered around the the life-cycle greenhouse gas emissions and petroleum consumption of biofuels relative to fossil fuels[10]. While greenhouse gas emissions and the consumption of fossil fuels are undoubtedly major factors when weighing options regarding the future of the automobile, internal combustion engines are also major contributors to air pollution. On-road mobile sources comprised 51% of Carbon Monoxide (CO), 29% of Hydrocarbons (HC), 34% of Nitrogen Oxides (NO_x), and 10% of particulate matter (PM) in the 1999 US National Emission Inventory[6]. Since air pollution is a major cause of death worldwide[23], any major regulatory decision involving internal combustion fuels should weigh the effect of potential options on air quality.

Ambient concentrations of atmospheric pollutants are dependent on a chaotic system that involves the emissions and deposition of the pollutants, atmospheric chemical reactions and meteorological phenomena. In order to accurately model the atmospheric pollutant concentrations, all the inputs to the system must first be modeled. One attempt has been made at such a model[12] for E85 (nominally 85% ethanol, 15% gasoline) but at the start of this study there had yet to be a comprehensive literature review and analysis of the emissions values on which the model depends. The current study aims to correct this shortcoming and supply parallel values for E10 (10% ethanol, 90% gasoline) and BD20 (20% biodiesel, 80% diesel) fuels.

2 Methodology

A literature search was performed for the emissions of E85, E10, and BD20 powered vehicles versus comparable petroleum powered vehicles using the Web of Science and SAE indexes, the EPA website, and Google Scholar. Any relevant citations in the articles retrieved by the primary search were also included. After completing the search, any studies that did not test paired vehicles (either a vehicle operating on both biofuel and gasoline or biofuel and gasoline vehicles of the same model) over a standard driving cycle (FTP or NEDC) or vehicles that were not road-certified were removed. Studies were also removed if the biofuel vehicles were not compared to Conventional Gasoline (CG), Reformulated Gasoline (RFG), or diesel. If a comprehensive review written since 2006 existed for a certain fuel type it was considered a sufficient source of information for that fuel and all other studies were discarded.

Data was then extracted from the remaining studies for volatile organic compounds (VOCs) including hydrocarbons (HC), total organic gas (TOG), hydrocarbons (NMHC), and non-methane organic gas (NMOG). VOC and TOG were considered to be identical, HC was considered to be the gases measured by a Flame Ionization Detector (FID) and not containing oxygenated or carbonyl groups, NMHC was considered to be HC with methane (CH_4) subtracted, and NMOG was considered to be TOG with CH_4 subtracted. If Organic Matter Hydrocarbon Equivalent (OMHCE) or Organic Matter non-Methane Hydrocarbon Equivalent (OMNMHCE) were reported, they were considered to be equivalent to TOG and NMOG, respectively. HC was considered equivalent to TOG and NMHC was considered equivalent to NMOG in gasoline vehicles, but not biofuel vehicles. Data was also extracted for Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Methane (CH_4), Carbon Dioxide (CO_2), Nitrous Oxide (N_2O), Formaldehyde (HCHO), Acetaldehyde (CH_3CHO), 1,3-Butadiene, Benzene, Toluene, 1-Pentene, Particulate Matter (PM) mass and number, and evaporative TOG, NMOG, and Benzene. Evaporative emissions are emissions detected in the air of a test cell while a vehicle is not running. Percent differences between biofuel and petroleum emissions were calculated using

$$\%Increase = \frac{BiofuelEmissions}{PetroleumEmissions} - 1 \tag{1}$$

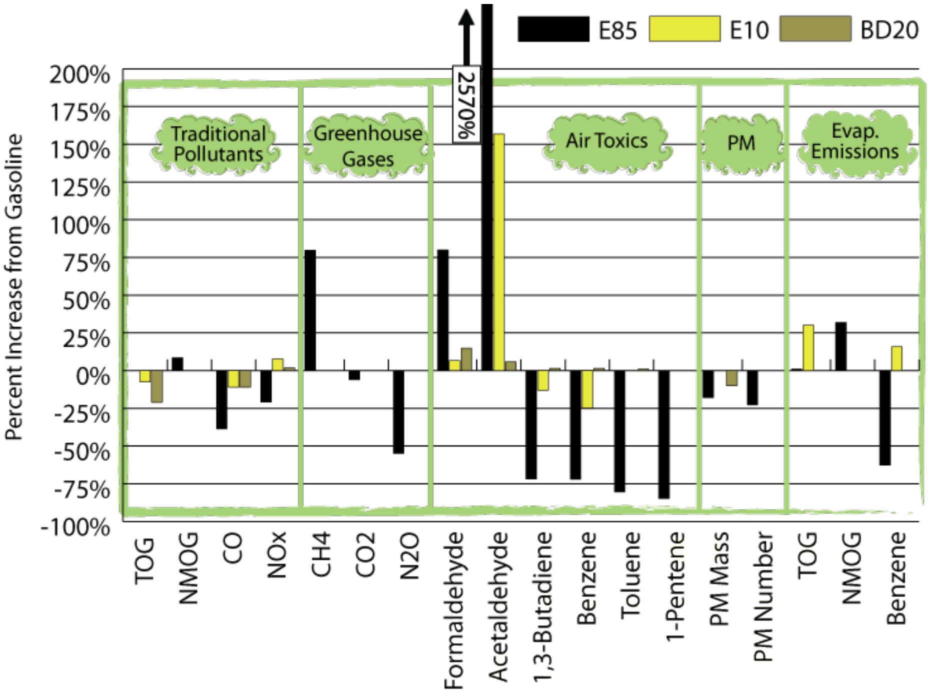

Figure 1: Percent emissions increase of E85, E10, and BD20 powered vehicle over petroleum equivalents

3 Results

3.1 E85

The literature search for E85 yielded 12 studies with a total of 43 vehicles tested[1, 3, 4, 11, 13, 14, 22, 19, 21, 17, 24, 2]. Data was also included from the EPA's vehicle emissions certification database[9] for 17 FFV's for sale in 2009 and one from 2007, giving a total of 61 vehicles. It should be noted that the reported values for the 2009 certification data are a weighted average of tailpipe and evaporative emissions.

Results are shown in Figure 1. TOG and NMOG emissions both exhibit small, non significant changes, and CH_4 shows a significant increase of 80% with E85 compared to gasoline. CO and NO_x both exhibit significant decreases of 27%, which is to be expected as the high oxygen level in E85 increases combustion efficiency which causes decreased CO emissions, and E85 burns at lower temperatures than gasoline which decreases NO_x emissions. The greenhouse gases (CO_2, N_2O, and CH_4) all decrease with E85, which agrees with theory because E85 has a lower carbon content than gasoline. The aldehydes (Formaldehyde and Acetaldehyde), both experienced large, significant increases with E85, 80 and 2570% respectively. The other toxics, 1,3-Butadiene, Benzene, Toluene, and 1-Pentene, all showed significant decreased emissions of 70-80% (exception: the reduction of 1-Pentene was only measured in one vehicle and therefore not significant). This agrees with theory because ethanol does not contain any of these compounds, and since E85 typically contains 20%

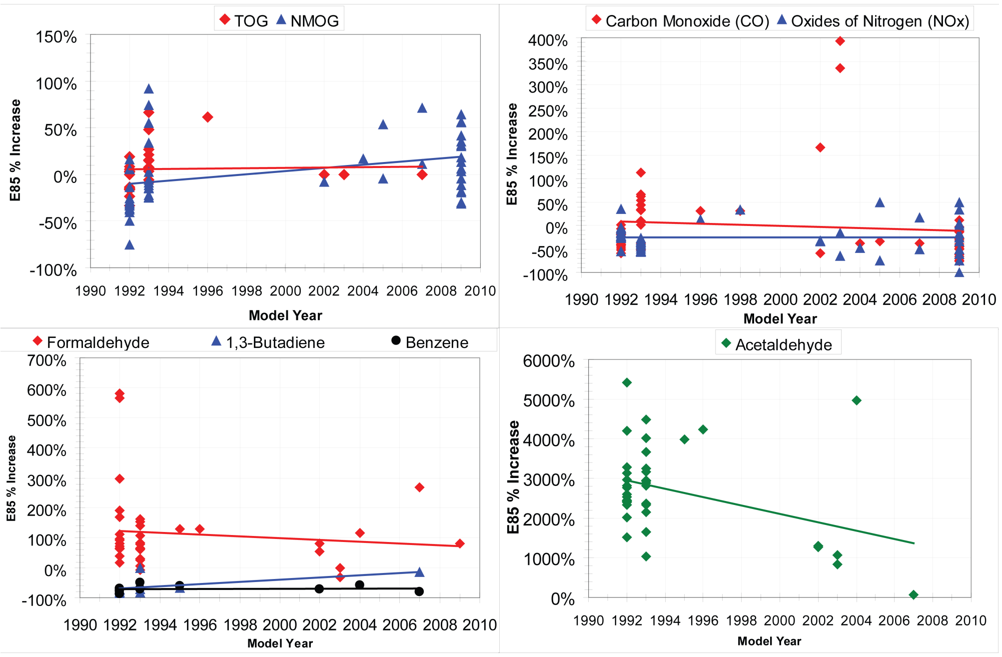

Figure 2: Variation of emissions differences with model year.

gasoline (the 85% ethanol is denatured with 5% gasoline), E85 should only emit approximately 20% of these pollutants as compared to conventional gasonline. Particulate matter and evaporative emissions (except Benzene, as discussed above) did not show significant changes.

Regressions were performed for E85 emissions difference vs. vehicle model year to determine any effects of new technology on the relative emissions of E85 and gasoline. As shown in Figure 2, no significant trends were found.

Figure 3 shows the number of studies and vehicles analyzed for each pollutant. It shows that for N_2O, Toluene, Pentene, PM, and evaporative emissions there is likely not enough data to make a conclusive statement about the effect of E85.

3.2 E10

The literature search for E10 yielded a 2007 report by the EPA[8]. In this report the EPA used a combination of their Predictive, Complex, and MOBILE6.2 models to compute a fleet-wide average difference in emissions between E10 and conventional gasoline. The inner workings of any of these models are beyond the scope of this study, but the results are shown in Figure 1. In general, E10 emissions follow the same general trends as to those of E85. One notable exception to this, however, is the evaporative emissions. Emissions of TOG and Benzene increased over conventional gasoline by 30 and 16%, respectively. The reason for this is that while pure ethanol has a lower vapor pressure than pure gasoline, a combination of the two has a higher vapor pressure than either component. This increased vapor pressure of E10 increases the volatility of the fuel and, hence, evaporative emissions. The other two

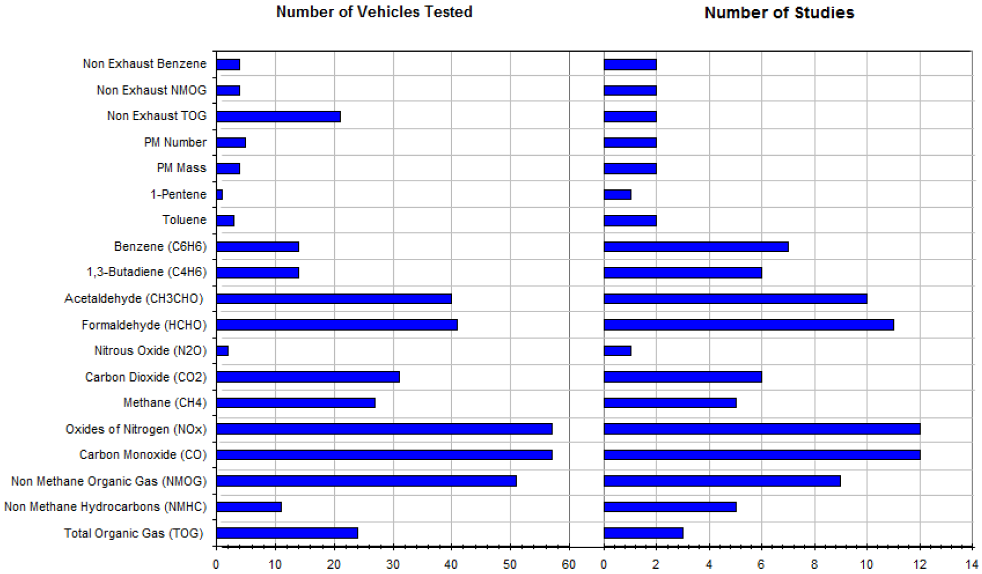

Figure 3: Number of studies and vehicles analyzed for each pollutant.

notable exceptions are TOG and NO_x. TOG decreases with E10 where it increases with E85, but the TOG data for E85 are inconclusive enough that this isn't necessarily a contradiction. NO_x increases with E10 where it decreases with E85, which does suggest a contradiction. It is possible that in E10 the extra oxygen content creates rich combustion conditions (rich combustion increases NO_x production) which offsets any decrease in NO_x caused by lower combustion temperature.

3.3 BD20

The literature search for BD20 yielded three literature reviews. The first was a 2002 Report by the EPA[7] that compiled a database of 822 measurements of HC, 827 measurements of CO, 864 measurements of NO_x, 834 measurements of PM, and 543 measurements of CO_2, mainly from heavy duty engines. The result of the report was a series of regressions for the percent change in pollutants for 0 - 100% biodiesel. The values for BD20 are presented in Figure 1. Two subsequent review articles[15, 20] upheld the values presented by the EPA with the exception of NO_x, for which significant scatter was reported around the 2% increase reported by the EPA. It was concluded that individual engines demonstrate a wide variation of NO_x emissions differences between BD20 and diesel, but the average effect is negligible.

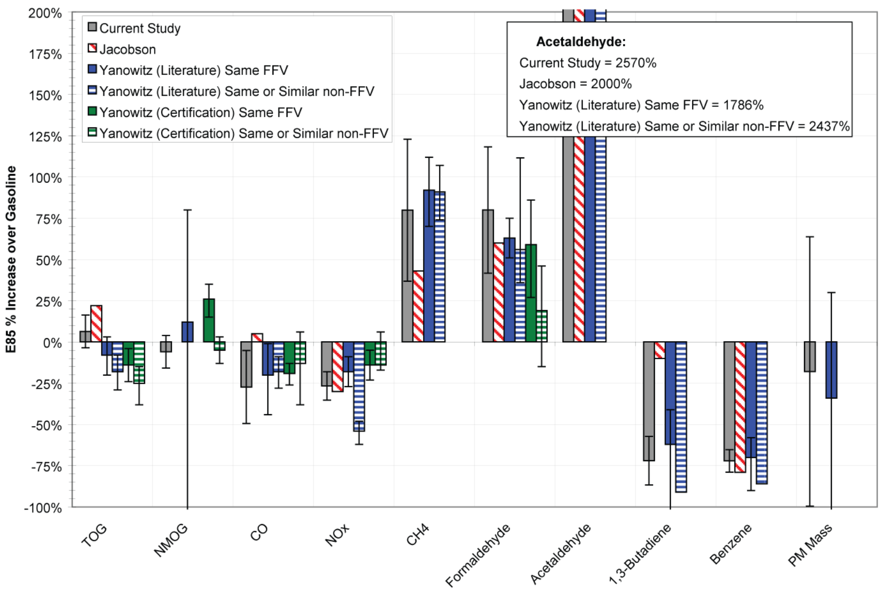

Figure 4: Comparison of E85 % emissions increase reported by different studies. Error bars represent 95% confidence intervals. Certification data values are reported as a weighted average of tailpipe and evaporative emissions.

4 Discussion

4.1 E85

Figure 4 compares the E85 emissions differences reported in this study to those by Jacobson[12] and another study by Yanowitz and McCormick[26] that was published while the current study was in preparation. Yanowitz and McCormick did a study very similar to the current study with much of the same data and methods. The main differences between the Yanowitz and McCormick study and this one are that Yanowitz and McCormick calculated geometric means for all percent differences where the current study reports medians, and Yanowitz and McCormick segregated the data between certification data and literature studies. They also segregated the data between studies that compared a single FFV running on E85 and gasoline and those that compared an FFV running on E85 and an identical or similar gasoline-only vehicle running on gasoline. These extra data analysis steps yielded significant results.

The first insight gained by the Yanowitz paper is that FFV vehicles burning gasoline have different, typically lower, emissions levels than same or similar gasoline-only vehicles, especially in TOG and NMOG. This effect is indirectly represented in Figure 4 and directly represented in the Yanowitz paper. This effect is most likely due more advanced combustion and emissions control equipment being used in FFVs. This difference raises the question of which comparison is more relevant in determining the real world emissions effect of switching gasoline vehicles to E85. Comparing E85 to gasoline in the same FFV is likely more representative of the physically-derived differences in emissions, but the presence of different technologies in different vehicles highlights the fact that manufacturers may often be capable of making cleaner cars than they do. Because of this it is possible that future emissions from internal combustion engines may be dictated more by the minimum standards in place than by fuel source.

The second insight gained from the Yanowitz paper is additional uncertainty in TOG and NMOG values. There are no consistent trends, especially in the case that since $TOG = NMOG + CH_4$, and CH_4 is positively correlated with E85 in all cases, TOG should be more positive (or less negative) than NMOG in all cases, but in the results it is more likely to be the opposite. From this one can only conclude that there is not enough evidence to conclude that E85 differs from gasoline in TOG or NMOG emissions. This can be contrasted with the 22% TOG increase with E85 assumed by a previous study[12].

4.2 E10 and BD20

Both E10 and BD20 cause relatively small changes in emissions compared to E85. Large scale use of E10 is likely to cause a significant increase in evaporative emissions if improved controls aren't required, but to make any conclusions about the overall implications of large scale use of either fuel would require air quality modeling.

5 Conclusions

This study has aimed to summarize the current state of knowledge of comparable emissions between biofuel and conventional fuel vehicles. While there is a certain degree of consensus of the relative emissions of E10 and BD20 fuels in comparison to conventional fuels, significant uncertainty exists around the emissions of E85 powered vehicles. In addition, it is possible that any inherent difference in emissions levels between E85 and gasoline may be negated by manufacturers only controlling emissions enough to meet the current standard regardless of what fuel they are using. More research is needed to reliably characterize emissions from E85-powered vehicles.

6 Acknowledgements

The authors would like to acknowledge anonymous reviews of an earlier version of this report.

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