MULTNOMAH COUNTY

MULTNOMAH COUNTY BIODIESEL TESTING ON HEAVY EQUIPMENT

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A REPORT FOR THE DEPARTMENT OF BUSINESS AND COMMUNITY SERVICES' FLEET AND SUSTAINABILITY PROGRAMS

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REPORT PREPARED BY:
MATT NICE
SENIOR RESEARCH AND EVALUATION ANALYST
EVALUATION/ RESEARCH UNIT
MULTNOMAH COUNTY, OREGON
503-988-3364

HTTP://WWW.CO.MULTNOMAH.OR.US/DBCS/BUDGET/PERFORMANCE

BIODIESEL TESTING ON HEAVY EQUIPMENT

EXECUTIVE SUMMARY

The Performance Management Group (PMG) was asked to analyze a small sample of data from Multnomah County heavy equipment which were tested using biodiesel fuel. Tests were conducted using a baseline-intervention design for various exhaust emissions on heavy equipment. The design had a single baseline test and three subsequent intervention tests conducted over several months. Results of the biodiesel emissions tests were mixed. Hydrocarbon levels appeared to be substantially reduced over baseline in the sample tested, consistent with reports by the EPA. Neither the carbon monoxide nor limited carbon dioxide data showed any significant changes. The particulate tests also showed no significant changes, however the data collected was flawed by increased error due to inconsistent sampling. If substantial policy decisions are to be made regarding biodiesel, ***PMG strongly recommends additional testing and clearly emphasizes that no policy decisions be made based solely on this report or the data contained within.***

BACKGROUND

The Performance Management Group (PMG) was asked to analyze a small sample of Multnomah County heavy equipment testing biodiesel. Biodiesel (B20) fuel is a blend of 20% biodiesel (B100 which is 100% refined bio product) and #2 diesel (normal vehicle fuel). The Biodiesel is a refined product and is derived from soybeans, mustard seed and leftover kitchen greases or fats. Tests were conducted using a baseline-intervention design for various exhaust emissions (4) on six pieces of Multnomah County heavy equipment.[1] The sampling design was a single baseline test and three subsequent intervention tests conducted at a five month, three month, and a one month intervals, respectively. The descriptive statistics for each emission test are listed in Table 1.

Table 1. Descriptive statistics for various emissions tests

			Intervention Tests				
	Statistic	Baseline	Biodiesel1	Biodiesel2	Biodiesel3	Biodiesel Avg. (1-3)	% Change
Hydrocarbon (PPM)	Mean	28.0	19.67	14.75	18.83	18.47	-34%*
	SD	8.34	3.93	4.19	6.24	5.13	
	N	6	6	4	6	6	
Carbon monoxide (PPM)	Mean	.0516	.0333	.0325	.0333	.0347	-33%
	SD	.0471	.0266	.0189	.0314	.0288	
	N	6	6	4	6	6	
Carbon dioxide (PPM)	Mean	1.487			1.575	1.575	+6%
	SD	.3322	na	na	.3973	.3973	
	N	6			6	6	
Particulate matter	Mean	.1400	.0086	.3042	.2122	.1496	+7%
	SD	.1422	.0113	.3862	.2571	.1939	
	N	6	6	4	6	6	

*Significant at .05.

[1] Note. While statistical testing can be performed on sample sizes this small, the likelihood of making either type-I or type-II errors is substantial. All statistical results should be viewed with extreme caution.

The emissions tested were hydrocarbon output parts per million (PPM), carbon monoxide (PPM), carbon dioxide (PPM), and particulate matter. With the exception of the particulate matter tests, each test was conducted under the same controlled environment by trained technicians.[2] Several missing cases were noted, especially with the carbon dioxide tests.

HYDROCARBON

Paired-sample *t*-tests were used to determine if the means of each test differed with subsequent tests (Figure 1).[3] The first paired-sample hydrocarbon test (baseline-biodiesel1) revealed a significant difference between the means, $t(5) = 3.353$, $p = .020$ (see Table 1). The average hydrocarbon output was 8.33 parts per million lower than baseline. The effect size (Cohen's *d*) was calculated at 1.37, identifying a large effect size.[4] Based on federal research results, we expected to identify a significant difference in hydrocarbon output with the use of biodiesel versus standard diesel. Based on theory, we did not expect a significant difference with each subsequent intervention (i.e., biodiesel2 and biodiesel3 should have similar results) because no changes in methodology were noted. The second test (biodiesel 1- biodiesel2) also identified significantly lower mean hydrocarbon output at intervention2, $t(3) = 4.977$, $p = .016$. Again, the effect size was found to be large ($d = 2.48$). The third test (biodiesel2- biodiesel3) again identified significant results, however in the opposite direction, $t(3) = -4.371$, $p = .022$, with a large effect size ($d = 2.18$). Thus, the third intervention actually exhibited significantly greater average hydrocarbons than did the second intervention.

Due to the significant and unexpected differences noted between each intervention, a single average measure for all hydrocarbon interventions was calculated and compared with the baseline test. Results found that overall, a significant reduction in the hydrocarbon emissions was noted while using biodiesel, $t(6) = 4.569$, $p = .006$. The effect size was large ($d = 1.86$). The average reduction in our sample was 9.53 PPM over baseline, or a 34% reduction.

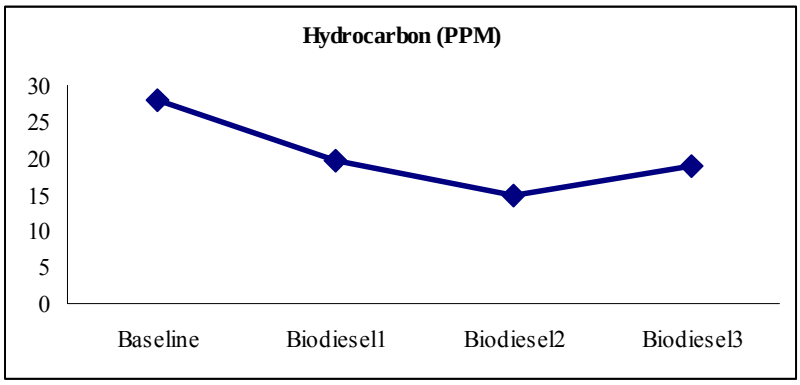

Figure 1. Hydrocarbon output baseline and with biodiesel.

[2] Several different technicians and various pieces of equipment for particulate matter tests were utilized.
[3] $\alpha = .05$
[4] Effect size is one way to determine magnitude of difference between groups. A difference between two groups could be statistically significant, but have a minuscule magnitude. Significance and magnitude should be reported together to convey overall difference, when appropriate.

Both the EPA and DOE identified hydrocarbon reductions with biodiesel over standard diesel. The EPA data suggested a 21% decline in hydrocarbon emission, while the DOE finds 11%. Two one-sample *t*-tests were performed based on the percent difference between baseline diesel and overall biodiesel, for each test value (EPA=.21 and DOE=.11). Results found that the percent change in our sample (-34%) was not significantly different than the EPA results, but was significantly different than the DOE results, $t(5) = -3.466$, $p = .018$. Thus, the hydrocarbon emission reduction was consistent with results from the EPA, and was better than DOE levels.

CARBON MONOXIDE

Consistent with hydrocarbons tests, carbon monoxide was tested in the same manner. Results in each individual paired-sample *t*-test reveal insignificant differences (e.g., baseline- biodiesel1, biodiesel1- biodiesel2, etc.), but neared significance in several cases (see Figure 2).[5] As with hydrocarbons, each of the intervention tests were averaged for a single biodiesel intervention point for each piece of equipment, and compared to baseline carbon monoxide emission. However, the results were found to be statistically non-significant, $t(5) = 1.963$, $p = .107$. While a substantial percent change was noted, it appears to be the product of an outlier in the sample.[6] Thus overall, no significant change in the carbon monoxide emissions was noted while using biodiesel. No further testing was performed.

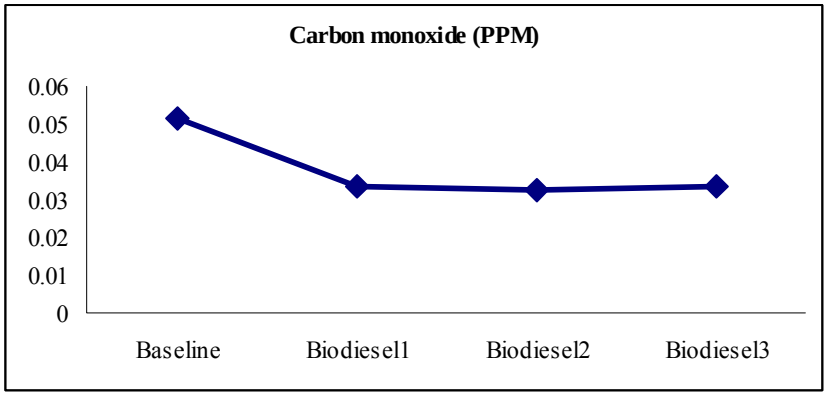

Figure 2. Carbon monoxide output baseline and with biodiesel.

CARBON DIOXIDE

As stated earlier, only two test points for carbon dioxide were identified (baseline-biodiesel3) and shown in Figure 3. This limits the number of tests that can be performed to a single paired-sample *t*-test. No significant change in the carbon dioxide emissions between diesel and biodiesel, $t(5) = -.712$, $p = .508$. No further testing was performed.

[5] $p = .058$, $p = .110$, and $p = .107$.

[6] One piece of heavy equipment was an outlier with CO^2 levels that were 5-times higher than the average for the group. This contributed to the large percent change and near significant results.

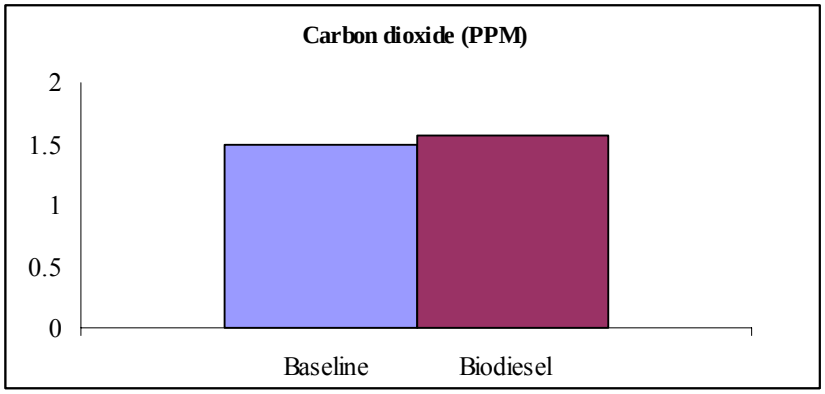

Figure 3. Carbon dioxide output baseline and with biodiesel.

PARTICULATE MATTER

As noted above, the particulate matter tests were performed inconsistently as compared to the other tests. This significantly detracts from statistical rigor, as various methods and device introduce inconsistent amounts of error. Figure 4 depicts the unusual results from the various tests. Because of this, the results from the following statistical tests should be interpreted with extreme caution. Paired-sample *t*-tests were performed consistent with hydrocarbons and carbon monoxide tests. Results in each individual paired-sample *t*-test revealed insignificant differences (e.g., baseline- biodiesel1, biodiesel1- biodiesel2, etc.). Each of the intervention tests were averaged for a single biodiesel intervention point for each piece of equipment, and compared to baseline emission levels. Again, the results were found to be statistically non-significant, $t(5) = -.712$, $p = .923$. Because of the various methods employed during the particulate sampling, no statistical conclusions will be drawn.

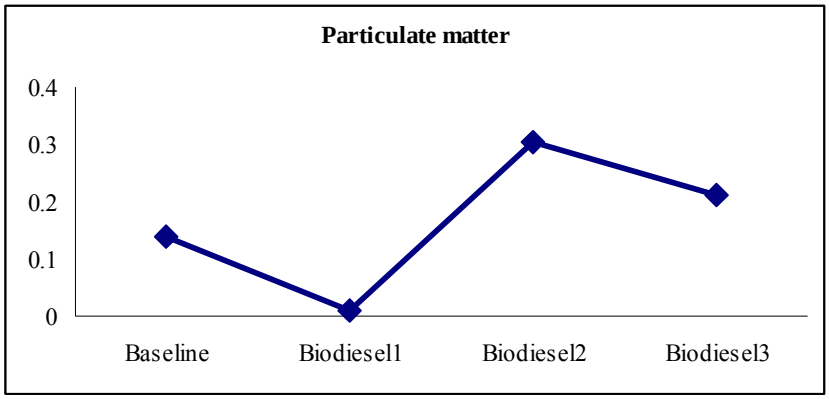

Figure 4. Particulate matter output baseline and with biodiesel.

CONCLUSIONS

Analysis of the biodiesel data showed mixed results. Hydrocarbon levels appeared to be substantially reduced over baseline in the sample tested. These were consistent with levels indicated by the EPA. While this result visually appeared with the carbon monoxide tests, it was likely a statistical anomaly due to an outlier reading from one pieces of equipment. Limitation to the data in the carbon dioxide reduced the number of tests that could be performed—no changes were detected. The particulate matter tests were numerous, however they were flawed by increased error due to inconsistent sampling methodology.

Several limitations to the information presented in this report should be noted. The extremely small sample size is one critical limitation which must be identified and cannot be over emphasized. This limitation leads to a host of statistical errors during interpretation. Future testing should employ a greater sample size, use a more consistent methodology, utilize additional data points (e.g., the average of three reading at each point), capture additional data (e.g., ambient temperature, number of miles between tests, hours in service), and have a return to baseline design.[7] If substantial policy decisions are to be made regarding biodiesel, ***PMG strongly recommends additional testing and clearly emphasizes that no policy decisions be made based solely on this report or the data contained within***.

[7] A return to baseline design helps to control for changes which may have occurred outside of the testing environment. For example, if all pieces received preventative maintenance (PM) service upon filling with biodiesel, performance may be enhanced regardless of the fuel.