U.S. Environmental Protection Agency
National Vehicle and Fuel Emissions Laboratory
Ann Arbor, Michigan

MEMORANDUM

DATE: September 27, 2001

TO: Docket for the Houston SIP/ Low Emission Diesel Rule

FROM: Cleophas Jackson

SUBJECT: Nonroad Diesel Engines Under 50 hp

The U.S. Environmental Protection Agency (U.S. EPA or the Agency) has analyzed the effects of changes in diesel fuel properties such as cetane number, sulfur content, and aromatics content, among other properties, on emissions of Oxides of Nitrogen (NOx), particulate matter (PM), and unburned hydrocarbon (HC). For purposes of this analysis the Agency is including in the highway engine based fuel effects impact assessment, nonroad diesel engines rated at over 50 hp. To the extent that the type of technology and calibration are similar to the highway counterpart(s) of the engine model being considered, the fuel effects could be assumed to mimic the heavy duty, highway based diesel fuel effects analysis' percent change results for NOx (Oxides of Nitrogen) emissions. The Agency funded an emissions study evaluating cycle / activity impacts on emissions of NOx, HC, PM, and CO, emissions from various nonroad diesel engines over different fuels. The goal of this testing effort was not validation of the analysis described in the Staff Discussion Document, "*Strategies and Issues in Correlating Diesel Fuel Properties with Emissions*". For that reason a consistent baseline fuel was not used in the study to generate isolated fuel specific data. The analysis of the admittedly limited data set (in the context of this effort) demonstrated that there is no reason to believe that nonroad engines over 50 hp would not react in a similar way (same trends) as the heavy duty highway engines included in the study with respect to the impact of fuel quality changes.

For engines rated below 50 hp, there are significant differences in the types of technology primarily employed by engine manufacturers that would allow for a potentially different impact on emissions associated with fuel quality changes. Under 50 hp engines are typically naturally aspirated[1] (99.87%) versus engines over 100 hp usually employ a turbocharger. Over 50 hp nonroad diesel engines tend to be direct injection engines (over 80%) and the majority of under 50 hp engines are indirect injection engines.[2] Smaller nonroad engines typically have a higher a surface area to combustion chamber volume ration that would cause manufacturers to design the fuel injection system and strategy to accommodate emissions control differently than would be done for larger horsepower engines. Spray impingement needs to be addressed differently for smaller engines thus impacting the design of the injectors and injection strategy. These effects may be seen in piston crown design, spray inclusion angle, among other design differences.

Due to the differences in engine design of the under 50 hp class, it would be difficult to extrapolate the impact of engine fuel property changes without a much larger body of data upon which to base the assessment. The body of data that exists for making the extrapolation above 50 hp is insufficient, on its own, to make a complete determination, however as a validation set, it does not contradict the results based on heavy duty highway diesel engines.

An analysis of the data collected by Southwest Research Institute for EPA Contract 68-C-98-169 WA 2-3[3], indicated that for engines over 50 hp, the predicted percentage change values seemed to track the observed percentage change values on an average basis as may be seen in Figures 1-3 below. It should be noted that engines below 50 hp are indicated using a circle around the data point. The data points for the under 50 hp engines are further from the reference line(s) than the data from the over 50 hp engines. The reference line represents the points at which predicted equals observed data. The raw data may be seen in attachment 1. It should be noted that the data included in the Unified Model was based primarily on highway engines exercised over heavy duty, highway cycles. The nonroad cycles (with different types of transient activity than the FTP) yielded similar percent changes in emissions for NOx, as did the observed FTP results. This would seem to indicate that percentage change in emissions associated with a fuel property change for NOx for nonroad diesel engines over 50 hp would be similar to a percentage change in NOx emissions for heavy duty highway engines with the same fuel property change. For the technical reasons stated above, the Agency is not able to make the extrapolation of the impacts of diesel fuel quality changes on emissions to under 50 hp nonroad diesel engines.

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[1] *Final Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines*, EPA 420-R-98-016, August 1998, Table 2-2

[2] Power Systems Research, 1997 OELink database

[3] *Transient and Steady State Emissions Testing of Ten Nonroad Diesel Engines Each Using Two Fuels,* Draft Final Report, August 2001

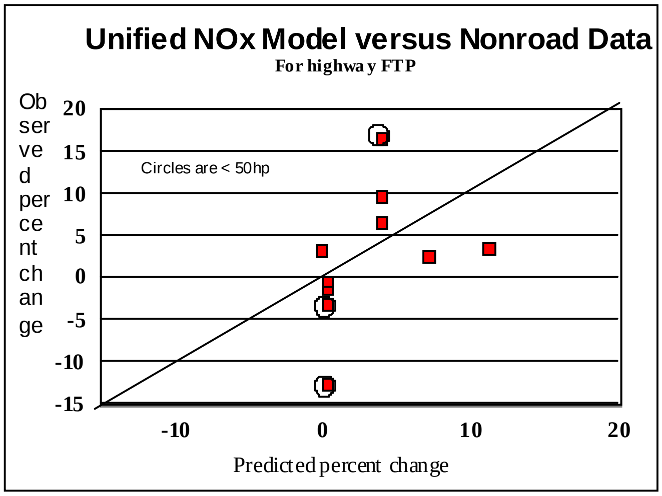

Figure 1. Highway FTP Based Comparison of Unified Model Predictions versus Nonroad Observed Data

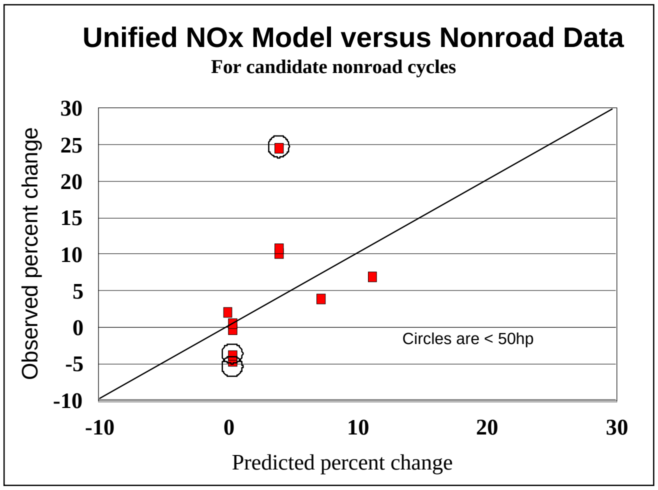

Figure 2. Nonroad Transient Cycle Based Comparison of Unified Model Predictions versus Nonroad Observed Data

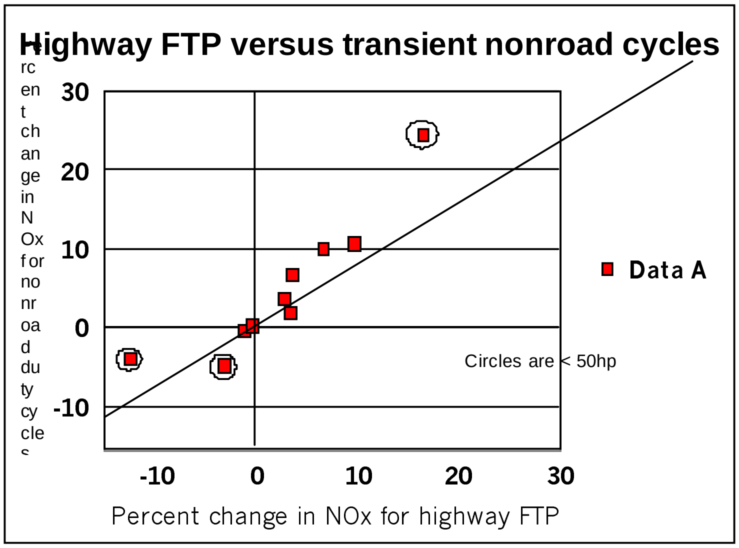

Figure 3. Comparison of Percent Change in NOx over the highway FTP versus the Nonroad Transient Cycles

Attachments: 2

ATTACHMENT 1
Raw Data

For each fuel pair-Difference Observed and Predicted NOx			
Fuel	Observed	Predicted	
2D-EC	6.45	11.21	-4.77
2D-NR	0.12	0.35	-0.23
CA-EC	3.83	7.22	-3.38
HS-CA	9.40	3.97	5.44
NR-CA	10.78	3.97	6.82
NR-HS	2.51	0.00	2.51
		AVE	1.06
		STD	4.69

Figure 1-1. NOx Fuel-Pair Differences

Difference Observed and Predicted NOx--Engines			
Engine #`	Observed	Predicted	Difference
1	-0.33	0.35	-0.68
2	6.45	11.21	-4.77
3	3.83	7.22	-3.38
4	9.40	3.97	5.44
5	10.78	3.97	6.82
6	2.51	0.00	2.51
9	0.51	0.35	0.15
		AVE	0.87
		STDDEV	4.31

Figure 1-2. NOx Differences by engine (two fuels per engine)

FTP Cycle-Difference Observed and Predicted NOx--Engines			
Engine #`	Observed	Predicted	Difference
1	-1.20	0.35	-1.56
2	3.58	11.21	-7.64
3	2.70	7.22	-4.52
4	6.64	3.97	2.68
5	9.79	3.97	5.82
6	3.37	0.00	3.37
9	-0.41	0.35	-0.77
		AVE	-0.37
		STD	4.71

Figure 1-3. NOx Differences by engine based on FTP Cycle Data

Non-FTP Cycle-Difference Observed and Predicted NOx--Engines			
Engine #`	Observed	Predicted	Difference
1	-0.15	0.35	-0.51
2	7.02	11.21	-4.19
3	4.06	7.22	-3.16
4	10.32	3.97	6.35
5	10.98	3.97	7.01
6	2.22	0.00	2.22
9	0.66	0.35	0.30
		AVE	1.15
SUMMARY OUTPUT		STDDEV	4.34

Figure 1-4. NOx Differences by engine based on NonFTP Data

ATTACHMENT 2
Nonroad Diesel Engine Study Fuel Properties

Test Method	Emissions Grade No. 2 Fuel "2D"	High-Sulfur Nonroad Fuel "NR"	California Vehicle Fuel "CA"	Clean California Fuel "EC"
D-2622 Sulfur, wt%	0.039	0.257	0.005	< 0.001
D-613 Cetane Number	48.0	46.1	53.0	68.3
D-1319 Aromatics	32.15	30.35	22.15	8.25
D-1319 Olefins	1.8	2.2	1.9	3.0
D-1319 Saturates	66.05	67.45	75.95	88.80
D-5186 Total Aromatics	35.3	31.9	25.2	12.6
PNA	11.10	9.55	3.25	2.20
D-2500 Cloud Point (°C)	-16	-16	-10	-2
D-4052 Specific Gravity	0.8444	0.8507	0.8294	0.8122
API	36.1	34.8	39.1	42.7
D-445 Viscosity (cSt @ 40°C)	2.515	2.765	2.430	2.920
D-482 Ash Content	< 0.001	< 0.001	< 0.001	< 0.001
D-524 Carbon Residue (10%)	0.085	0.155	0.070	0.040
D-5291 Carbon (wt%)	86.65	86.15	85.83	85.44
D-5291 Hydrogen (wt%)	13.08	13.00	13.58	14.19
D-93 Flash Point (°F)	143	161	163	178
D-976 Cetane Index	48.7	47.4	51.7	62.6
D-4737 Cetane Index	48.2	46.9	52.6	67.0
D-86 Distillation (°F)				
IBP	333	353	368	409
5%	389	387	397	428
10%	409	411	407	440
15%	428	429	419	451
20%	444	444	429	461
30%	468	470	449	483
40%	488	492	468	504
50%	505	511	489	524
60%	523	531	512	543
70%	541	552	538	562
80%	563	578	566	584
90%	594	613	603	614