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New Technology Research & Development Program
Grant Contract 582-5-70807-0017

Task 2 Deliverable Report

The preparation of this report is based on work funded in part
by the State of Texas through a Grant from the
Texas Commission on Environmental Quality.

NTRD 2005-1; Contract No. 582-70807-0017 Task #2

Ms. Kate Williams
TCEQ Grant Manager
TCEQ MC-204, Building F
12100 Park 35 Circle
Austin, TX 78753

January 10, 2007

Subject: Task #2 Fuel Optimization

Dear Kate:

Per the contract, I am attaching the requested report for task #2(645E3B Engine) contract No. 582-5-70807-0017.

Sincerely Yours,

Mark Davis
Systems Engineer
Diesel Engine
GE Infrastructure Rail

GE imagination at work

The Preparation of this report is based on work funded in part by the state of Texas through a Grant from the Texas Commission on Environmental Quality

Task #2 Fuel Optimization FTP Data for EMD 16-645E3B Tier II Engine

Summary:

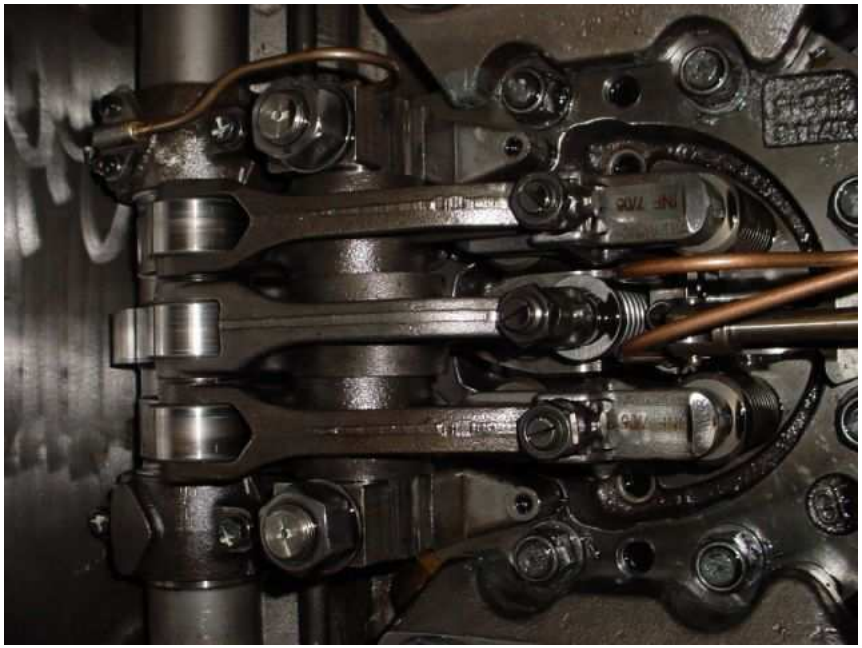
1. **After running a TDC baseline FTP test with production hardware, a 20 hour full load break in was performed. The static injector timing was reset and a 2nd FTP was run.**
2. **Increasing the compression ratio and reducing the turbo nozzle ring area was thought to increase overall combustion efficiency. The expected results varied greatly from the actual outcome of testing. Data was taken at different retarded timings. At these data points NOx trended downward while PM and smoke increased. An optimized camshaft was needed to keep the appropriate portion of the cam profile in use during the injection event both from a performance and reliability point of view.**
3. **Prior to testing configuration 7, the original pistons were placed back into the engine. Multiple emission tests were conducted to understand which components affect NOx reduction.**
4. **After reviewing the initial test data and the 645E Tier II program data, it was decided to utilize our variable retarded injector that was initially developed for our 645E3B Tier 0 solution. This injector in combination with optimized cam shafts, plateau honed liners, special rings and counter flow after cooling would increase the probability of meeting Tier 2 NOx with Tier 0 PM, HC, CO and smoke.**
5. **The first attempt at testing the final configuration failed due to some faulty injectors. The second attempt was more favorable because the injectors were replaced and recheck twice for leakage. Please see enclosed data.**

Photo of Variable Timed Injectors

Configuration 11 & Final Configuration Injector

Photo of Optimized Cams

Optimized Cams Used in Configurations 1-7, 10, 11 & Final



Tier II 16-645E Engine Results Summary

Trial #	Desc.	Static Timing	LH BSFC	LH Nox	LH P	S BSFC	S Nox	S P	N8 Nox	N8 P	N8 Smoke	N8 A/F	N8 BSFC	PFP psi	PIP psi	Hz Stress Mpa	BOI (btdc)	I Dur	Exh T F
1	9200 S	4	0.427	13.3	0.32	0.471	13.5	0.31	13	0.32	9	35	0.404	1183	16800		18.5	23.5	745
2	9200 S	0	0.432	12.8	0.49	0.481	13.1	0.55	12.5	0.47	6	35	0.409	1110	15600		15.5	24	750
3	9200 S	-6	0.448	6.6	0.54	0.483	6.6	0.5	6.6	0.48	12	33	0.428	929	13500		10	25.5	814
4	9200 P	-6	0.444	7	0.38	0.482	7	0.42	7	0.32	8	35	0.421	878	15900	1302	9	24	801
5	9200 P	-9	0.492	5.3	2.53	0.536	5.6	3.38	5.1	1.13	22	31	0.458	789	14700	1278	6	25.5	890
6	9335 P	-6	0.439	8	0.38	0.475	9.7	0.34	7.2	0.39	14	34	0.419	928	15000	1387	7.5	19	796
7	9335 P	-9	0.451	6.6	0.46	0.47	8.1	0.37	6.1	0.51	15	33	0.44	886	14900	1450	5	18.5	842
8	9335 P	-12	0.476	5.2	1.33	0.487	6.6	0.68	4.5	1.75	31	32	0.47	752	14100	1463	1.5	19.5	932
9	9335T P	-6	0.43	8.3	0.34	0.46	10.1	0.31	7.1	0.34	11	32	0.412	980	19900	1569			832
10	9335T P	-9	0.456	6.9	0.58	0.472	8.5	0.39	6.1	0.72	21	30	0.449	871	20000	1685			930
11	9335T P	-12	0.469	5.8	0.75	0.479	7.2	0.43	5	0.98	25	30	0.463	764	18800	1666			930
Goal				5.5	0.6		8.1	0.72			30								

9200 S injector (0.421 plunger) with standard cams

9200 P injector with optimized cams

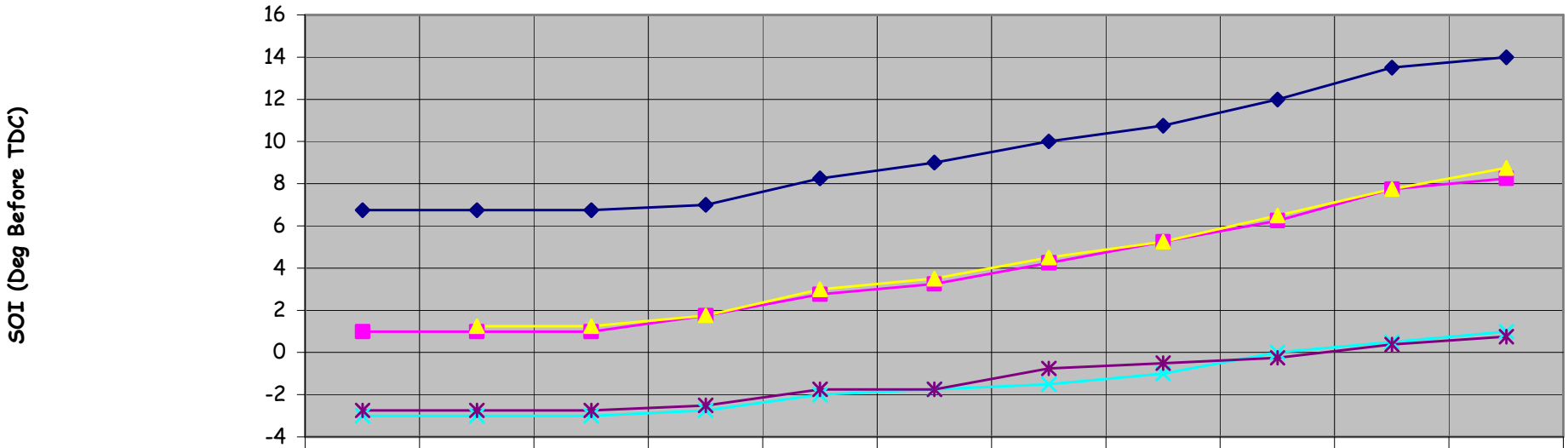
9335 P injector (0.500 plunger) with optimized cams

9335T P injector with reduced flow tip and optimized cams

645E3B Engine Uses Same Cam Profile as 645E Engine!!

GE imagination at work

UP1 654E3B T-II NOx SOI Data



	LI	I	DB-2	1	2	3	4	5	6	7	8
Configuration #1	6.8	6.8	6.8	7.0	8.3	9.0	10.0	10.8	12.0	13.5	14.0
Configuration #3	1.0	1.0	1.0	1.8	2.8	3.3	4.3	5.3	6.3	7.8	8.3
Configuration #4		1.3	1.3	1.8	3.0	3.5	4.5	5.3	6.5	7.8	8.8
Configuration #11	-3.0	-3.0	-3.0	-2.8	-2.0	-1.8	-1.5	-1.0	0.0	0.5	1.0
Final Configuration	-2.8	-2.8	-2.8	-2.5	-1.8	-1.8	-0.8	-0.5	-0.3	0.4	0.8

Notch

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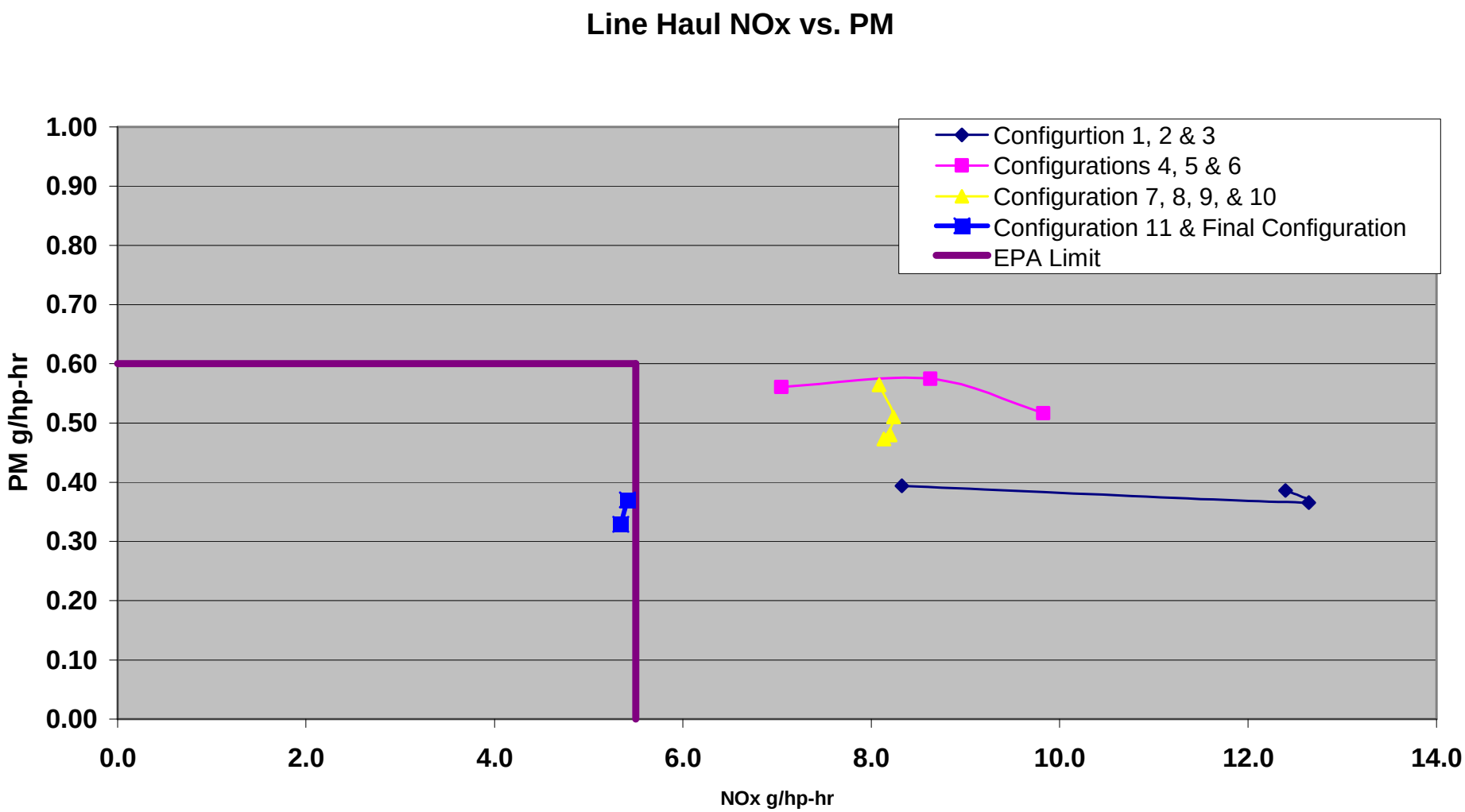
Results of Testing Line Haul Cycle



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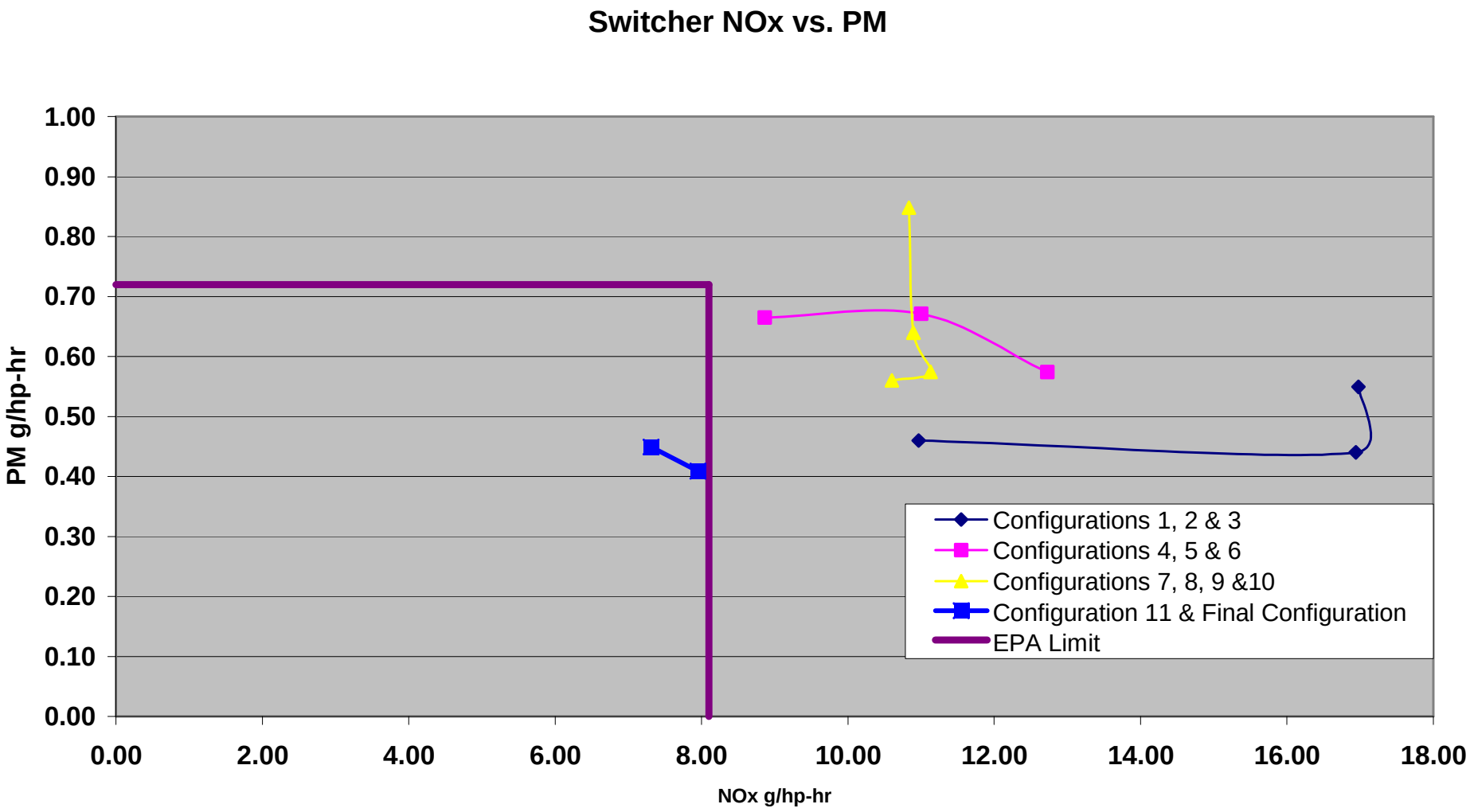
Results of Testing Switcher Cycle



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Tier II NOx 16-645E3B Engine Test Results

FTP Results

"UP1-E3B" engine (EMD 16-645-E3B Tier II NOx)

	Freight Cycle					Switch Cycle				
	bsfc lb/hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	bsfc lb/hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr
Configuration #1	0.382	0.53	1.0	12.4	0.39	0.477	1.00	0.92	16.98	0.55
Configuration #2	0.375	0.41	0.6	12.6	0.37	0.466	0.82	0.72	16.94	0.44
Configuration #3	0.378	0.48	0.7	8.3	0.39	0.463	0.77	0.84	10.97	0.46
Configuration #4	0.381	0.52	0.6	9.8	0.52	0.471	0.91	0.82	12.73	0.57
Configuration #5	0.384	0.56	0.7	8.6	0.57	0.475	0.94	0.98	11.00	0.67
Configuration #6	0.390	0.53	0.8	7.0	0.56	0.472	0.81	1.09	8.86	0.67
Configuration #7	0.372	0.52	0.7	8.1	0.56	0.466	0.81	1.07	10.84	0.85
Configuration #8	0.382	0.63	0.8	8.2	0.51	0.471	1.14	1.26	10.89	0.64
Configuration #9	0.386	0.52	1.1	8.1	0.47	0.464	0.90	1.11	11.13	0.57
Configuration #10	0.383	0.49	0.8	8.2	0.48	0.468	0.82	1.10	10.60	0.56
Configuration #11	0.408	1.05	1.0	5.3	0.33	0.489	1.83	1.34	7.95	0.41
Final Configuration	**0.398**	**0.69**	**0.9**	**5.4**	**0.37**	**0.461**	**1.44**	**1.35**	**7.31**	**0.45**

GE imagination at work

Tier II NOx 16-645E3B Engine Test Results

FTP Results "Smoke"

Test Configuration	Smoke Opacity		
	Max SS	30-Sec	3-Sec
Configuration #1	9%	11%	15%
Configuration #2	5%	6%	8%
Configuration #3	7%	14%	17%
Configuration #4	8%	12%	18%
Configuration #5	16%	20%	28%
Configuration #6	19%	24%	39%
Configuration #7	9%	12%	24%
Configuration #8	15%	19%	36%
Configuration #9	12%	21%	28%
Configuration #10	13%	20%	30%
Configuration #11	28%	34%	46%
Final Configuration	**23%**	**30%**	**36%**

NTRD 2005-1; Contract No. 582-70807-0017

Ms. Kate Williams
TCEQ Grant Manager
TCEQ MC-204, Building F
12100 Park 35 Circle
Austin, TX 78753

March 10, 2007

Subject: Task #2 Fuel Optimization

Dear Kate:

Per the contract, I am attaching the requested report for task #2(710G3A Engine) contract No. 582-5-70807-0017.

Sincerely Yours,

Mark Davis
Systems Engineer
Diesel Engine
GE Infrastructure Rail

GE imagination at work

NTRD 2005-1; Contract No. 582-70807-0017

The Preparation of this report is based on work funded in part by the state of Texas through a Grant from the Texas Commission on Environmental Quality

GE imagination at work

Task #2 Fuel Optimization FTP Data for EMD 16-710G3A Tier II Engine

Summary:

1. **After running configuration #1 FTP test with production hardware, a 20 hour full load break in was performed. The static injector timing was reset and configuration #2 FTP was run.**
2. **For performance mapping purposes six different notch 8 points comparing three different static timing settings were run. (Configuration #3-8) This was done to understand the effects timing retard with regards to emissions and get strain gauged rocker arm data to understand fuel cam location with respect to the injection event.**
3. **Prior to configuration #11 FTP test, the standard injectors were replaced with a special development set of injectors. These injectors along with the cam change and turbocharger change reduced NOx significantly compared to the standard hardware kit. The penalty was an increase in visible emissions (smoke) greater than allowed by EPA limits.**
4. **To understand the data from Configuration #11, four more notch 8 points were run at two different timing settings to verify test equipment variability and test repeatability. (Configuration #12-15) The additional points verified configuration #11 to be good data and also pointed out that the NOx does not meet tier II levels and the visible emissions (smoke) is exceeding the tier 0 limits at sea level.**
5. **One final FTP (configuration #16) was conducted to verify the trend of emissions, NOx and smoke, with respect to advancing the timing from configuration #11.**

Tier II NOx Components

710G3A Injector

Re-Phased Cams

Tier II 16-645E Engine Results Summary

Trial #	Desc.	Static Timing	LH BSFC	LH Nox	LH P	S BSFC	S Nox	S P	N8 Nox	N8 P	N8 Smoke	N8 A/F	N8 BSFC	PFP psi	PIP psi	Hz Stress Mpa	BOI (btdc)	I Dur	Exh T F
1	9200 S	4	0.427	13.3	0.32	0.471	13.5	0.31	13	0.32	9	35	0.404	1183	16800		18.5	23.5	745
2	9200 S	0	0.432	12.8	0.49	0.481	13.1	0.55	12.5	0.47	6	35	0.409	1110	15600		15.5	24	750
3	9200 S	-6	0.448	6.6	0.54	0.483	6.6	0.5	6.6	0.48	12	33	0.428	929	13500		10	25.5	814
4	9200 P	-6	0.444	7	0.38	0.482	7	0.42	7	0.32	8	35	0.421	878	15900	1302	9	24	801
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6	9335 P	-6	0.439	8	0.38	0.475	9.7	0.34	7.2	0.39	14	34	0.419	928	15000	1387	7.5	19	796
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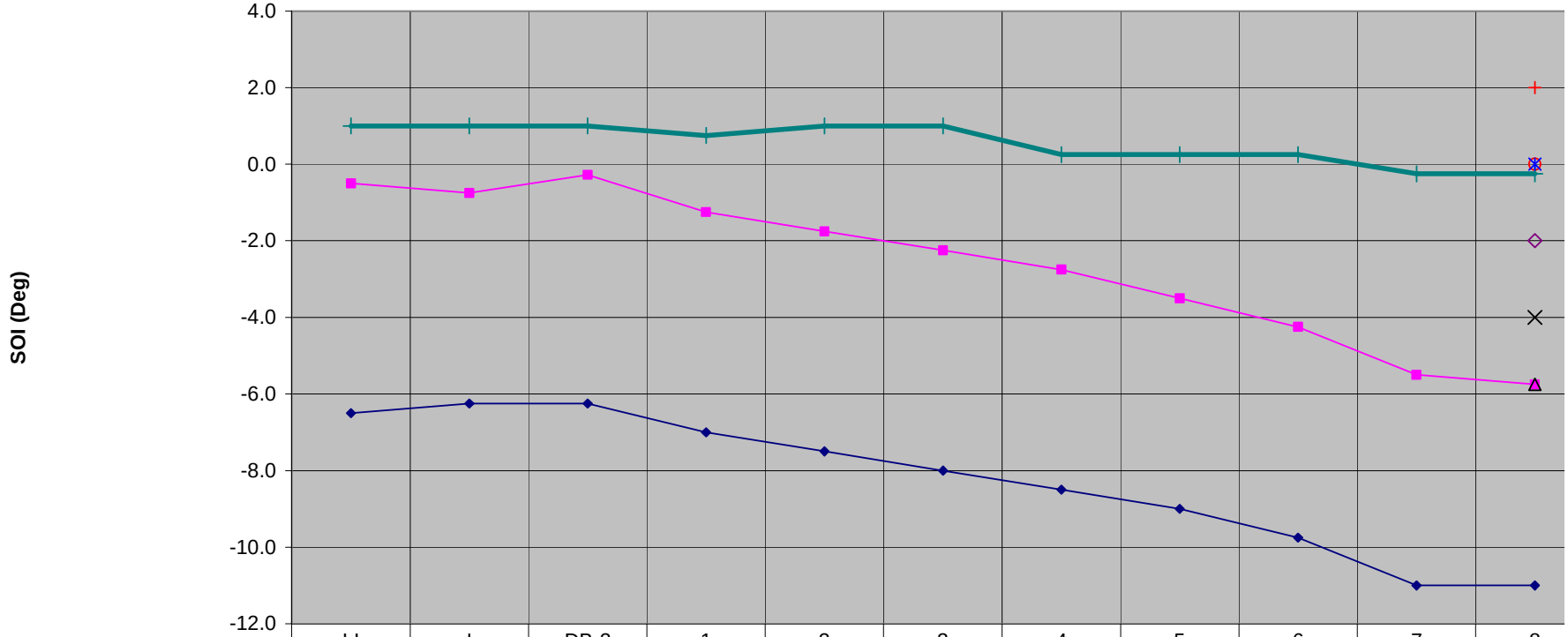
8	9335 P	-12	0.476	5.2	1.33	0.487	6.6	0.68	4.5	1.75	31	32	0.47	752	14100	1463	1.5	19.5	932
9	9335T P	-6	0.43	8.3	0.34	0.46	10.1	0.31	7.1	0.34	11	32	0.412	980	19900	1569			832
10	9335T P	-9	0.456	6.9	0.58	0.472	8.5	0.39	6.1	0.72	21	30	0.449	871	20000	1685			930
11	9335T P	-12	0.469	5.8	0.75	0.479	7.2	0.43	5	0.98	25	30	0.463	764	18800	1666			930
Goal				5.5	0.6		8.1	0.72			30								

9200 S	5229200 injector (0.421 plunger) with standard cam
9200 P	5229200 injector with re-phased cam
9335 P	5229335 injector (0.500 plunger) with re-phased cam
9335T P	5229335 injector with reduced flow tip and re-phased cam

710G3A Engine Uses Same Cam Profile as 645E Engine!!

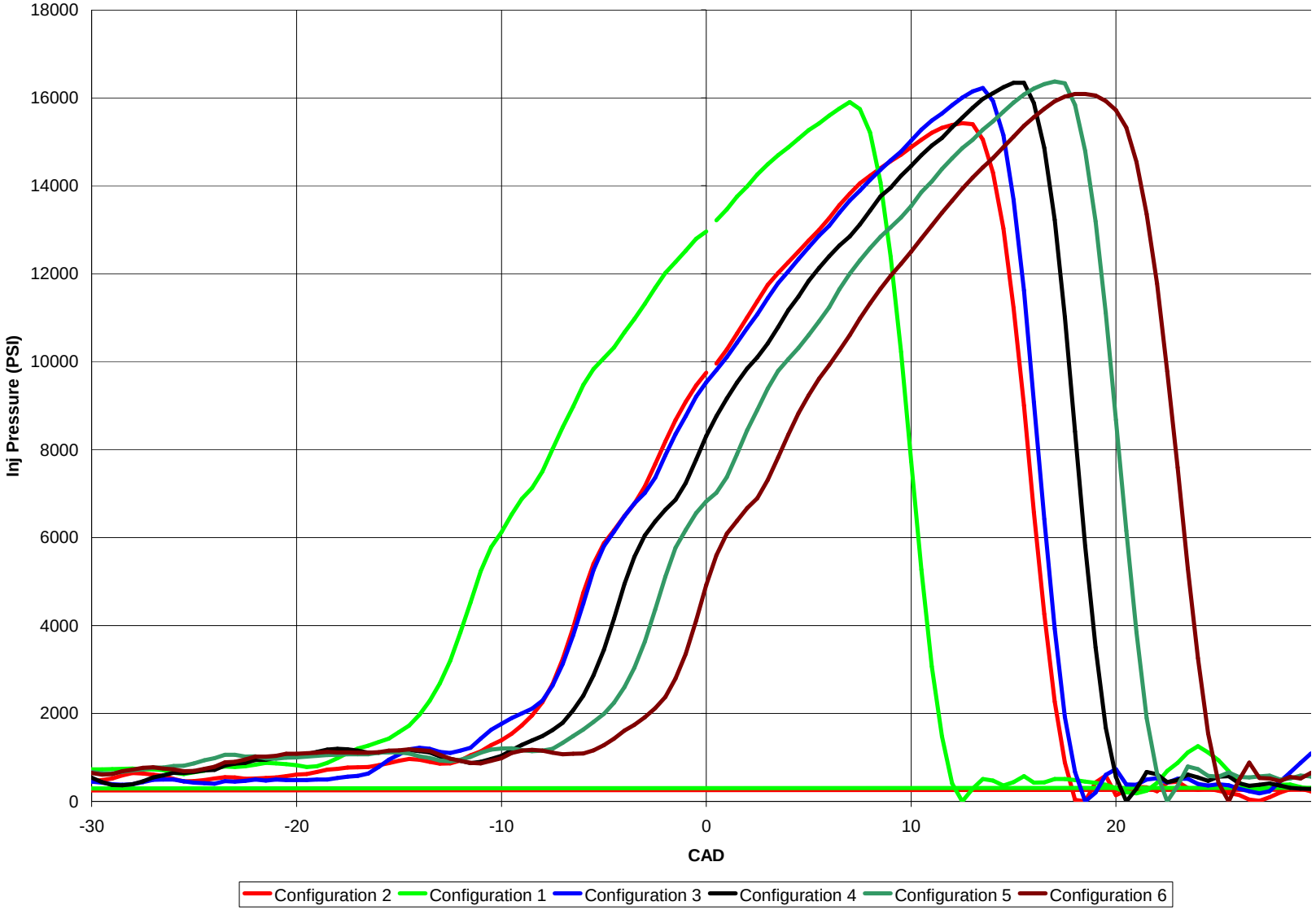
Start of Injection



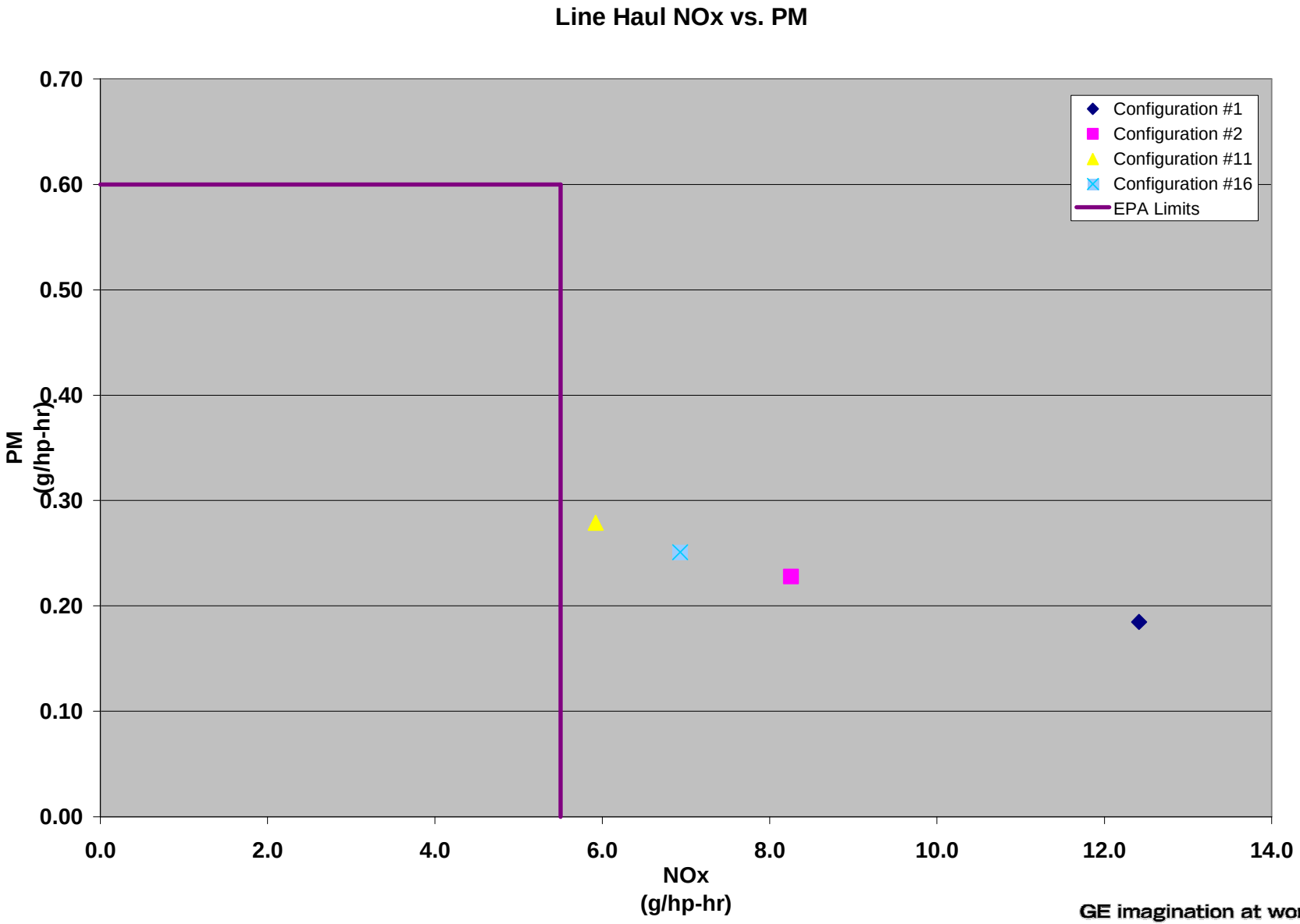
	LI	I	DB-2	1	2	3	4	5	6	7	8
Configuration 1	-6.5	-6.3	-6.3	-7.0	-7.5	-8.0	-8.5	-9.0	-9.8	-11.0	-11.0
Configuration 2	-0.5	-0.8	-0.3	-1.3	-1.8	-2.3	-2.8	-3.5	-4.3	-5.5	-5.8
Configuration 3 & 4											-5.8
Configuration 5 & 6											-4.0
Configuration 7 & 8											-2.0
Configuration 9 &10											0.0
Configuration 11	1.0	1.0	1.0	0.8	1.0	1.0	0.3	0.3	0.3	-0.3	-0.3
Configuration 12 & 13											0.0
Configuration 14 & 15											2.0

Notch

Injection Pressure vs. Cam Angle



Results of Testing Line Haul Cycle



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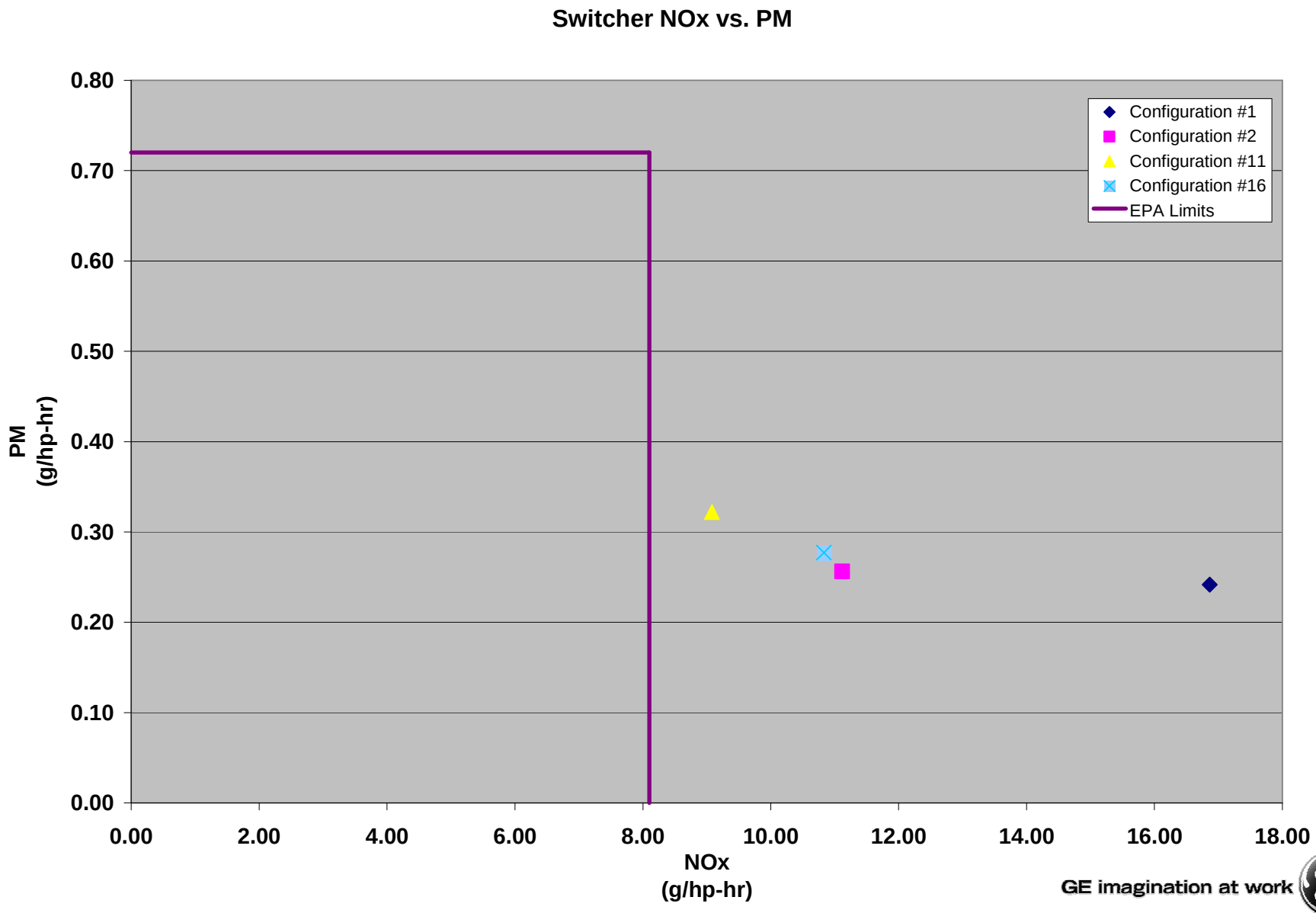
Results of Testing Switcher Cycle



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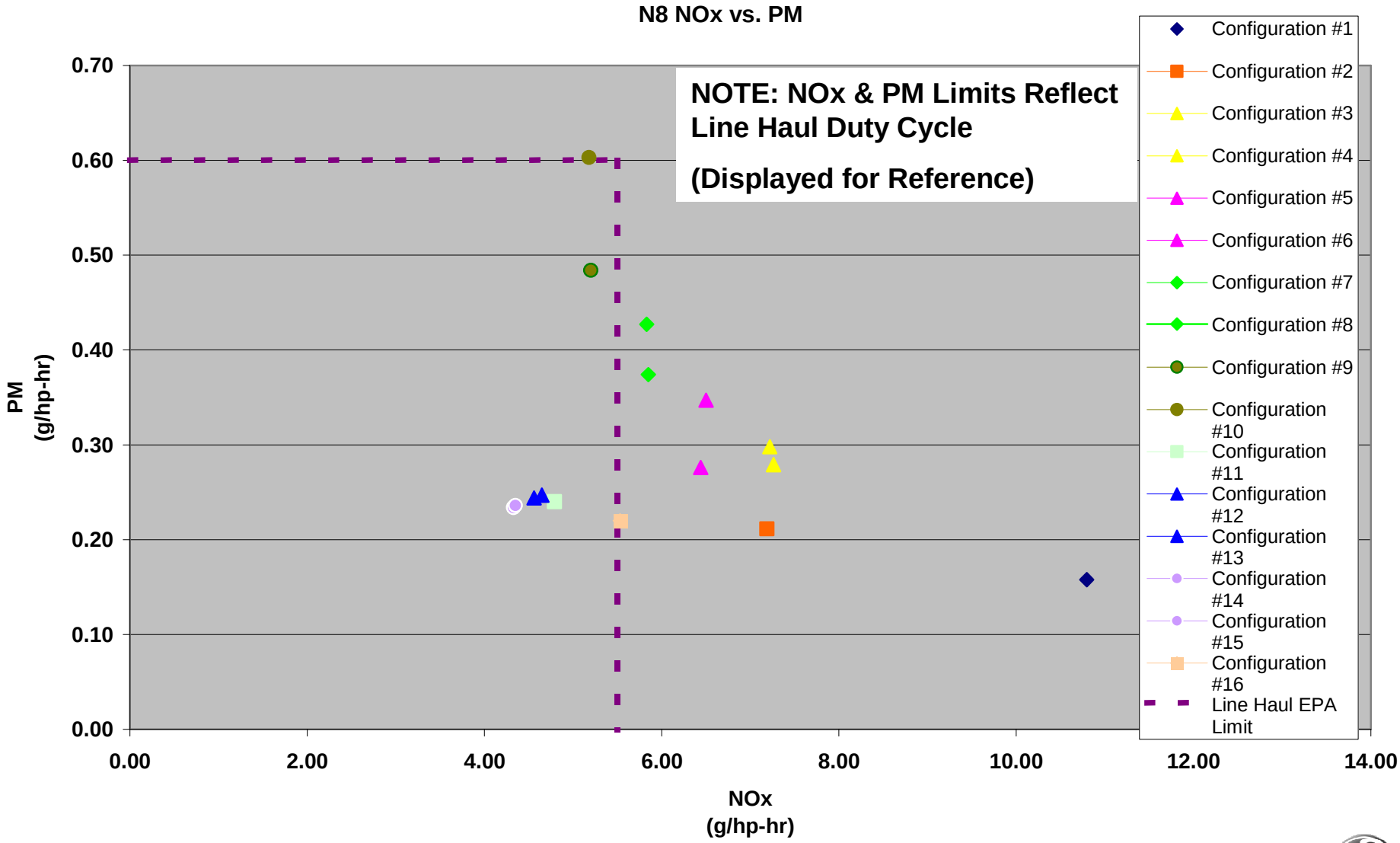
Results of Testing N8 Points



Tier II NOx 16-710G3A Engine Test Results

FTP Results

	Freight Cycle					Switch Cycle					Notch 8 results					
	bsfc lb/hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	bsfc lb/hp-hr	HC g/hp-hr	CO g/hp-hr	NOx g/hp-hr	PM g/hp-hr	Power	AAR-Corr bsfc	HC	CO	Corr. NOx	PM
Configuration #1	0.371	0.28	0.9	12.4	0.18	0.424	0.46	0.64	16.86	0.24	4035.5	0.354	0.22	0.93	10.80	0.158
Configuration #2	0.376	0.29	0.8	8.3	0.23	0.430	0.44	0.78	11.12	0.26	4046.8	0.359	0.25	0.72	7.19	0.211
Configuration #3	-	-	-	-	-	-	-	-	-	-	4041.5	0.361	0.26	0.57	7.22	0.298
Configuration #4	-	-	-	-	-	-	-	-	-	-	4051	0.360	0.27	0.59	7.26	0.279
Configuration #5	-	-	-	-	-	-	-	-	-	-	4052.6	0.366	0.27	0.59	6.44	0.276
Configuration #6	-	-	-	-	-	-	-	-	-	-	4052.2	0.366	0.30	0.58	6.50	0.347
Configuration #7	-	-	-	-	-	-	-	-	-	-	3969.2	0.376	0.35	0.53	5.85	0.374
Configuration #8	-	-	-	-	-	-	-	-	-	-	3980.9	0.375	0.32	0.53	5.83	0.427
Configuration #9	-	-	-	-	-	-	-	-	-	-	4018.6	0.388	0.38	0.53	5.20	0.484
Configuration #10	-	-	-	-	-	-	-	-	-	-	4036.7	0.386	0.39	0.52	5.18	0.603
Configuration #11	0.409	0.35	1.1	5.9	0.28	0.454	0.58	1.00	9.08	0.32	3931	0.393	0.27	0.95	4.79	0.240
Configuration #12	-	-	-	-	-	-	-	-	-	-	3906	0.394	0.22	1.15	4.56	0.244
Configuration #13	-	-	-	-	-	-	-	-	-	-	3906	0.393	0.23	1.14	4.65	0.247
Configuration #14	-	-	-	-	-	-	-	-	-	-	3812	0.401	0.21	0.96	4.33	0.234
Configuration #15	-	-	-	-	-	-	-	-	-	-	3807	0.401	0.23	0.93	4.35	0.236
Configuration #16	0.394	0.28	1.12	6.93	0.251	0.443	0.45	0.89	10.83	0.277	4092.6	0.377	0.22	1.02	5.53	0.220

Tier II NOx 16-710G3A Engine Test Results

FTP Results "Smoke"

	FTP Smoke Test		
	Max SS	30-Sec	3-Sec
Configuration #1	6%	8%	12%
Configuration #2	9%	18%	23%
Configuration #3	12%	N8 Only	
Configuration #4	12%	N8 Only	
Configuration #5	13%	N8 Only	
Configuration #6	14%	N8 Only	
Configuration #7	15%	N8 Only	
Configuration #8	15%	N8 Only	
Configuration #9	8%	N8 Only	
Configuration #10	8%	N8 Only	
Configuration #11	22%	40%	60%
Configuration #12	10%	N8 Only	
Configuration #13	10%	N8 Only	
Configuration #14	9%	N8 Only	
Configuration #15	9%	N8 Only	
Configuration #16	17%	30%	38%