GRPE/WHDC/FE35

EMA testing to address WHDC GTR Options

(Addendum to EMA's Low NOx Variability Program)

Shirish A Shimpi

June 9 2009

Engine Manufacturers Association®

EMA Low NO_x Measurement Variability Program
Used as a Starting point for the WHDC work

Objective:

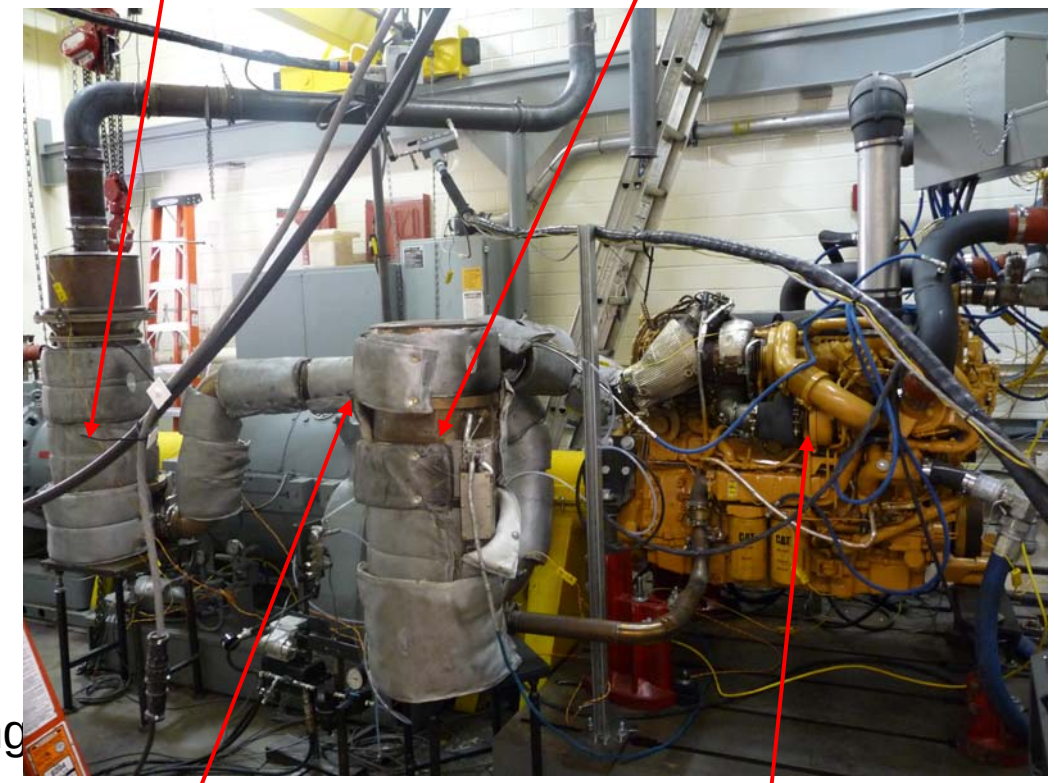
- Compare Available Methods of NO_x Measurement at U.S. 2010 Emission Levels (0.20 g/hp-hr)
  - Dilute Continuous (current HD default method)
  - Dilute Bag (current LD default method)
  - Raw Continuous

- Key Questions
  - Does one of these methods show a clear advantage with respect to variability ?

Engine Manufacturers Association®

Test Article

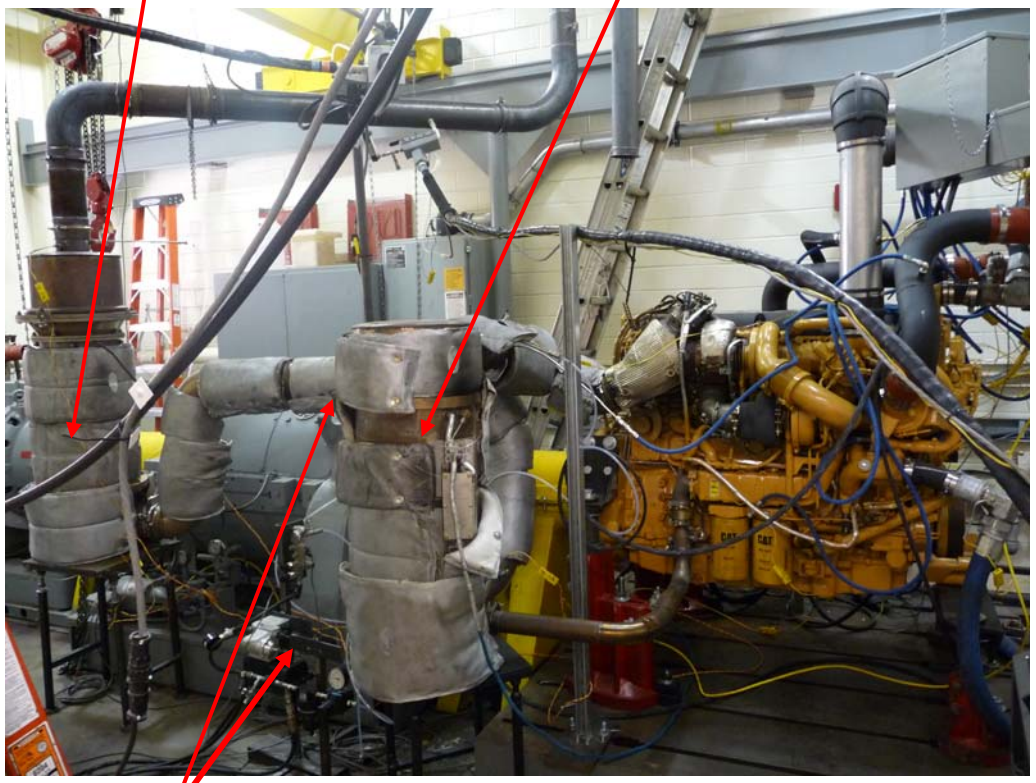
- Test Engine
  - Production 2008 MY Caterpillar C13
  - 350hp @ 1800 rpm
  - 1350 lb-ft @ 1200 rpm
  - ~ 1.1 g/hp-hr NO_x
- Production DPF
  - catalyzed soot filter
- Production Regeneration System
  - Caterpillar CRS (burner)
- SwRI added SCR and urea dosing system to reach 2010 levels



Engine Manufacturers Association®

Aftertreatment System Details

- SCR Downstream of DPF
- Zeolite SCR Catalysts
  - Fe-Zeolite followed by Cu-based “Low Temp” Zeolite
- Urea Dosing
  - Air-Assisted
  - Model-Based Feed Forward Controller
  - Engine-out NO_x Sensor
- No Slip Catalyst
- NH3 Slip Targets
  - 10 ppm cycle average
  - 25 ppm peak



Engine Manufacturers Association®

EMA Low NO_x Measurement Variability Program

Testing Notes (also followed for WHDC work):

- All measurement systems run simultaneously
- CFR 40 Part 1065 procedures used for all measurements
- Preperations for each test day includes regeneration and Part 1065 pre-conditioning before overnight soak
- Catalysts are “de-greened” but still fresh
  - DPF regeneration conducted bypassing SCR catalysts to prevent degradation and keep AT performance repeatable

Engine Manufacturers Association®

EMA Low NO_x Measurement Variability Program Measurement Setup

- Dilute Continuous
  - Full-flow CVS dilution tunnel
  - Horiba MEXA 7200D bench with AIA-720MA NO_x running Dry
- Dilute Bag (Not used for the WHDC work)
  - Sampled from same tunnel as above
  - Heated bag system at 40C to prevent condensation (includes all sample lines)
  - Bag bench is also Horiba MEXA 7200D, bags are read Wet
  - Incorporated significant amount of current LD “best practice”
- Raw Continuous
  - MEXA 7100DEGR – AIA 720MA NO_x running Dry
  - Intake Air Flow via LFE
  - Exhaust flow via 1065 calculations (chemical balance)

WHTC Addendum to Low NOx Program

- Test 1 – Comparison of WHTC to FTP
  - Preliminary work for EMA's needs for setup and WHTC test familiarity
  - Added single day of cold and multiple hots to compare
  - Controller was NOT recalibrated for WHTC, run as is
- Test 2 – WHTC fuels comparison
  - EU spec fuel and US spec fuel provided by EC
  - 3 days of repeat hot-start testing
    - Triplicate runs on each fuel per day
- Test 3 – WHTC soak time testing
  - Compare 10-minute and 20-minutes soak times
  - 2 days of testing cold-start and 8 hots
  - Alternate 10-min and 20-min soak periods

WHTC Addendum Test 1
WHTC vs FTP comparison

Cycle	Day	Cold	Hot 1	Hot 2	Hot 3	Hot 4	Hot 5	Hot 6	Hot 7	Hot 8
FTP	1	0.538	0.090	0.082	0.087	0.079	0.095	0.064	0.070	0.083
	2	0.557	0.091	0.081	0.065	0.058	0.058	0.057	0.060	0.057
	3	0.541	0.091	0.066	0.075	0.068	0.066	0.071	0.084	0.095
	Avg	0.545	0.091	0.076	0.076	0.068	0.073	0.064	0.071	0.078
		Hot Average	**0.075**	**Composite (Hot-Avg)**		**0.142**	**Composite (1st-Hot)**		**0.156**	
WHTC	1	0.706	0.145	0.135	0.124	0.147	0.112	0.097	0.074	0.054
		Hot Average	**0.111**	**Composite (Hot-Avg)**		**0.196**	**Composite (1st-Hot)**		**0.225**	

- Dosing controller was NOT changed or recalibrated between FTP and WHTC tests
- For this test 20-minutes hot soaks were used and 1/7 cold + 6/7 hot weighting was applied
- Preliminary analysis of Engine Out (EO) NO_x Sensor data indicates “similar” cycle EO NO_x (~ 1.1 to 1.2 g/hp-hr)
  - Hot conversions (from 1.1) FTP = 93%, WHTC = 90%
- More detailed analysis of continuous data needed

WHTC Addendum Test 2
WHTC Fuels Comparison – Fuel Properties

Description			Fuel 1	Fuel 2	Low NOx Prog 2D Cert Fuel
			U.S. Spec	E.U. Spec	
SwRI Fuel Code			EM-6901-F	EM-6902-F	EM-6491-F
Property	Method	Units			
Aromatics	D-1319	vol%			**30.6**
Aromatics	D-5186	vol%	**33.3**	**24.4**	
PAHs	D-5186	vol%	11.6	5.5	
Cetane Number	D-613		**47.4**	**53.2**	**46.5**
Density		kg/L	0.847	0.834	0.844
Viscosity	D-445	cSt-40C	2.670	2.95	2.6
Sulfur	D-5453	ppm wt	9	2	9
Nitrogen	D-4629	ppm wt	< 1	< 1	< 1
Distillation	D-86	deg C			
IBP			197	208	171
10%			226	233	204
50%			271	274	243
90%			312	319	293
EBP			332	349	321
Flashpoint	D-93	deg C	83	89	74
Carbon	D-5291	%wt	0.867	0.863	0.878
Hydrogen	D-5291	%wt	0.129	0.136	0.116

Engine Manufacturers Association®

WHTC Addendum Test 2
WHTC Fuels Comparison – Results

Morning			Afternoon			Difference
Average	Stdev	CVar	Average	Stdev	CVar	
0.119	0.0176	14.7%	0.151	0.0043	2.9%	0.031
0.190	0.0129	6.8%	0.135	0.0145	10.8%	0.055
0.095	0.0039	4.1%	0.148	0.0075	5.0%	0.053

	EU	**U.S.**
Day 1	0.119	0.151
Day 2	0.135	0.190
Day 3	0.095	0.148
Average	**0.117**	**0.163**
Overall Stdev	0.0208	0.0218
Overall Cvar	18%	13%
Final Difference		0.047

- Note: Preliminary analysis of NO_x Sensor data does indicate higher Engine out NO_x on U.S. spec fuel (~7%)
  - More detailed analysis still in progress

Engine Manufacturers Association®

WHTC Addendum Test 3
WHTC Soak Time Comparison

	Cold	Hot 1	Hot 2	Hot 3	Hot 4	Hot 5	Hot 6	Hot 7	Hot 8
Soak Length		10-min	20-min	10-min	20-min	10-min	20-min	10-min	20-min
Day 1	0.628	0.145	0.156	0.099	0.131	0.090	0.119	0.079	0.115
Soak Length		20-min	10-min	20-min	10-min	20-min	10-min	20-min	10-min
Day 2	0.735	0.141	0.103	0.107	0.094	0.112	0.083	0.091	0.042
		10-min	0.092						
		20-min	0.121	0.030					

- Hot-start conversion (1.27 g/hp-hr NOx Engine-out)
  - 10-min soak = 93 %
  - 20-min soak = 90 %

Engine Manufacturers Association®